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Commercial Thinning in Steep, Mountains
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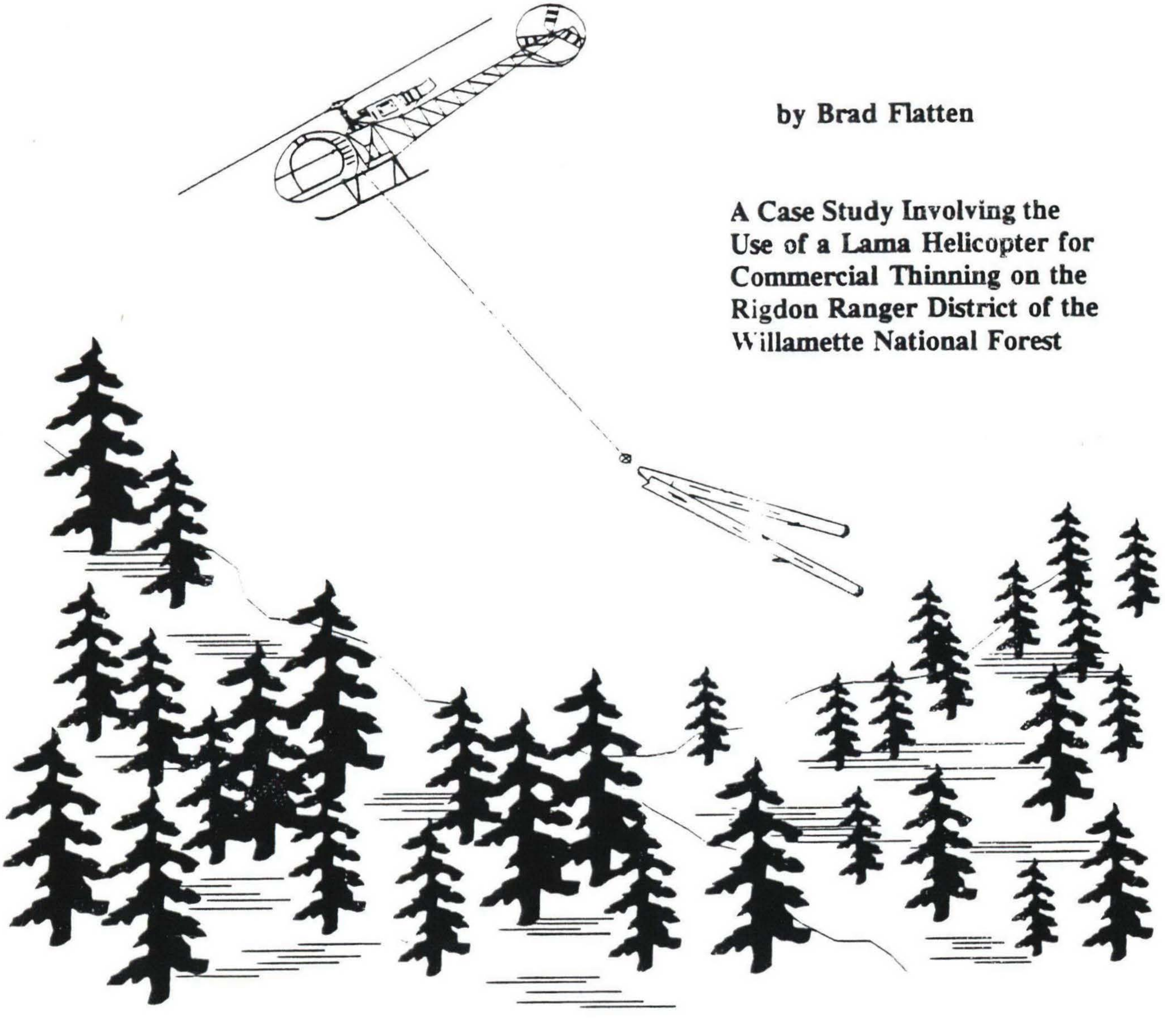
The Use of Small Helicopters for Commercial Thinning in Steep, Mountainous Terrain



by Brad Flatten

A Case Study Involving the
Use of a Lama Helicopter for
Commercial Thinning on the
Rigdon Ranger District of the
Willamette National Forest

THE USE OF SMALL HELICOPTERS FOR COMMERCIAL THINNING IN STEEP, MOUNTAINOUS TERRAIN

by

Lloyd Bradley Flatten

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A great deal of research has taken place in an effort to find more economically efficient yarding systems for commercial thinnings. Almost all of this research has centered on tractors or small yarders with limited capabilities in terms of long yarding distances. The purpose of this study is to determine whether using helicopters can be an economical alternative for commercial thinning in steep, mountainous terrain. The study area consists of a second-growth stand of Douglas-fir and mixed true fir species. The stand was thinned using a Lama SA-315B helicopter (external lifting capacity of 2500 lbs.) to yard a total of 383 mbf (800.5 cunits) over a period of 3 weeks. Average yarding distance was approximately 2500 feet and the average slope was 40%. The diameter of the trees removed averaged 15 inches and the average piece size was approximately 87 board feet (.182 cunits).

Gross production data were kept by the project manager for the logging company. This information is used to compare costs actually experienced during the operation with costs that might have occurred had the stand been cable yarded. The stand had originally been planned for uphill cable yarding using intermediate supports. A Thunderbird TMY 50 yarder is used as the hypothetical comparison operation.

A detailed time study was conducted and the results are used to evaluate the effects of turn weights and yarding distance on the helicopter operation. Regression equations were developed and used to predict hook time, haul time, and total turn time for specific conditions.

A damage survey was conducted after yarding to assess the condition of the residual stand. Results of this survey are compared with the amount of damage predicted for a cable system using a regression formula developed by Caccavano (1982).

The results of the study indicate that using the Lama helicopter can be an economically feasible alternative for commercial thinning. An average yarding cost per thousand board feet of $179.21 was estimated for the helicopter operation; the cable system would have cost an estimated $159.73 per mbf for yarding, with an additional $55.21 per mbf for necessary road and landing construction. The helicopter yarding resulted in no damage to the residual stand. An estimated 44.6 sq. ft. of scar area per acre would have resulted had the stand been cable yarded.

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THE USE OF SMALL HELICOPTERS FOR COMMERCIAL THINNING IN STEEP, MOUNTAINOUS TERRAIN

1.0 INTRODUCTION

The importance of second growth management to the timber industry of the Pacific Northwest will grow dramatically within the next several decades. Harvest of trees from the 11 inch to the 15 inch diameter classes will become a major percentage of the annual cut in the region (Aulerich, 1975; Tedder, 1979). Much of this volume will need to come from commercial thinning of young stands.

Because of the steep, mountainous terrain of much of the Pacific Northwest, many stands were initially clearcut harvested using large yarders. These yarders typically have towers 90 feet in height or taller and line capacities which enable them to yard distances well over 2000 feet. As a result, road systems which were developed during this initial harvest commonly have road spacing of 2000 feet or greater.

Much research has been done to evaluate the most cost effective means of small wood harvesting, and particularly thinning (Aulerich, 1975; Kellogg, 1980). Nearly all of this research has centered on ground vehicles or small cable systems. A compendium of the currently available production studies for cable systems by Aubuchon (1982) indicates no commercial thinning study where maximum external yarding distances exceeded 1200 feet. Most thinning studies in fact, had average yarding distances considerably less than 500 feet. Other conditions which are conspicuously lacking in current research are thinnings which involved downhill yarding or intermediate support configurations.

An important consideration when thinning in steep terrain is the possibility of residual tree damage due to the logging operation. Several studies have shown that both steeper slopes and larger machine size may contribute to the amount of damage to the residual stand when thinning (Caccavano, 1982). Levels as high as 25 to 50 percent of the residual stand with some degree of damage are not uncommon. Downhill thinning in particular can result in substantial damage. In one study, damage levels as high as 74% of the residual stand were reported (Burditt, 1981). According to Caccavano, another important factor contributing to greater stand damage is the presence of thin barked, true fir species in the residual stand. The areas where these species are most likely found (high elevation) are unfortunately also the areas which usually have the steepest slopes and a road spacing which requires larger machines.

The economic implications of residual stand damage caused by thinning has not been well researched. Damage studies are typically only a side issue attached to production studies. Froehlich (1976) noted that very little loss in wood production results when wounds remain uninfected. However, in some cases the percentage of wounds which become infected can be quite high. The perception that residual stand damage is negating the possible benefits of thinning is causing some silviculturists within Region 6 (Washington and Oregon) of the U.S.D.A. Forest Service to avoid thinnings (Mann, unpublished 1988).

What type of harvesting systems are currently available for thinning in those areas where road spacing precludes the use of small or medium sized yarders? Are downhill yarding and intermediate support configurations simply too costly to consider in a second-growth harvest operation? Several studies indicate production rates for downhill thinning to be 25 - 50% less than for uphill systems. Several obvious alternatives are available to the land manager. The use of large yarders for commercial thinning is most likely uneconomical and may result in substantial damage to the residual stand. Building midslope roads so that smaller, lower cost yarders can be used is perhaps a better option. Or, if road costs are too high, foregoing commercial thinning entirely may be the most economic alternative.

The purpose of this study is: 1) to determine whether using small helicopters (in particular the Lama SA 315b) can be an economic alternative for commercial thinning in steep, mountainous terrain, and 2) to determine what factors contribute to or detract from the productivity of the helicopter system.

In order to satisfy the first objective the results of a completed thinning operation using a Lama helicopter are compared to hypothetical cable yarding results. Yarding costs, road building requirements, and protection of the residual stand during yarding are considered. Costs are then weighed against the likely revenues to determine whether the helicopter logging system is economically feasible.

The second objective is met by an analysis of the results from a detailed time study. Statistical methods are used to determine which factors most affect both hook and inhaul times.

2.0 HELICOPTER DESCRIPTION

Helicopters were first used for logging during the early 1970's (Binkley, 1973). Since then, the helicopters typically used for logging have included the Sikorsky S-64, S-61, and S-58, the Boeing Vertol 107-II, and the Bell 214 and 212 (USDA Forest Service, 1986). These craft represent a wide range of lifting capabilities with external payload ratings from 4,200 to 25,000 pounds. The Lama SA 315B in comparison has a external payload capacity of only 2,500 pounds (see table 1). A larger payload capacity usually requires a larger and more powerful helicopter. The hourly costs of operating a larger craft are significantly greater. Both larger support crew requirements and higher hourly fuel consumption add to the already expensive ownership costs of the larger helicopters. As a result, operating costs for large helicopters can be extremely high relative to other logging equipment (yarders).

In order for larger helicopters to be competitive with less expensive cable systems, their hourly production must be significantly higher. In old-growth timber, involving clearcut settings, or shelterwood cuts with widely spaced residual trees, helicopter systems can at times be competitive. The ability to piece together optimal turn sizes is crucial in making the operation economically feasible. The difficulty in achieving profitable turn sizes in partial cut settings, and at the same time protecting the residual stand, has been the primary reason why larger helicopters have not been used for commercial thinnings.

In a study by Dykstra, et. al., (1978) a medium lift Puma helicopter (6700 lb. lifting capacity) was used to thin a 21 acre unit on the Siuslaw National Forest in Oregon. Horses were used to prebunch the logs in an effort to make more efficient use of the helicopter. The authors had anticipated the difficulties in achieving profitable turn sizes in a thinning. The combination of a smaller helicopter and prebunching was used in an effort to alleviate this problem. Unfortunately, everyone involved in the helicopter operation was inexperienced and the study was conducted over a short time period (two days). The resulting total logging cost (1978 dollars) was $265 per mbf which was considered to be excessive at that time.

Rocky Mountain Helicopters, Inc. logged the stand which is the subject of this study. They began using Lama helicopters for logging in 1984 and are currently using 3 of the craft for logging in the Pacific Northwest. The Lama SA 315B is manufactured by Aerospatiale Helicopter Corporation (see table 2 for specifications). It is a small helicopter with relatively low hourly costs and a payload capacity which is well suited for logging small piece sizes. For this reason, it has been used primarily for logging stands consisting of smaller second-growth material. While primarily used for clearcut and salvage logging over the past several years they have also been used to log thinnings.

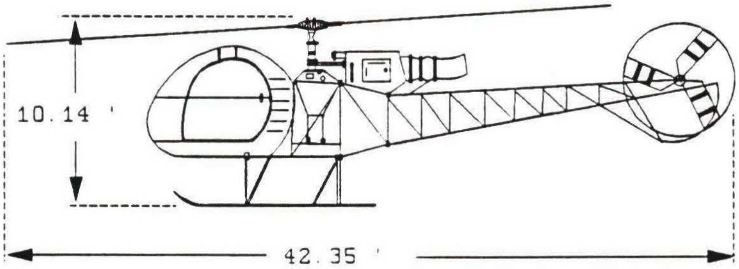
Basic Characteristics of Helicopters Commonly Used for Logging *

Characteristic	Make of Helicopter S-64	214B	107-II	S-61	212	S-58	Lama
Performance:							
Max. Speed (mph)	127	115	167	150	132	150	130
Service Ceiling (ft.)	10,000	11,300	10,000	12,500	17,400	15,000	17,720
Fuel Consumption (gal./ hr.)	395	200	180	150	---	110	60
Engines							
Number	2	1	2	2	1	2	1
Max. Horsepower	4,500	2,930	1,350	1,500	900	910	858
Weights (lbs.):							
Gross Weight	42,000	16,000	19,000	19,000	11,200	13,000	4,300
Approx. Payload (external lift @ sea level)	20,000	7,400	8,000	8,500	4,200	5,000	2,500
Dimensions (nearest ft.):							
Fuselage Length	70	45	45	61	42	39	34
Main Rotor Diameter	72	50	50	62	48	56	36
Overall Length (with rotors)	89	61	83	73	57	51	42
Overall Height	25	14	17	18	13	16	10

* Taken from U.S.D.A. Forest Service Publication, 1986
except for Lama information which is from Aerospatiale publication, 1986.

Table 1 - A Comparison of Helicopter Specifications

LAMA SA 315B



SA 315B Lama Profile

Standard Configuration Empty Weight including Engine Oil, lbs	2,266
Useful Load, lbs	2,034
Maximum Gross Weight, lbs	4,300
PERFORMANCE - Sea Level, Standard Conditions at Maximum Gross Weight	
Maximum Speed (Vne), mph	130
Maximum Cruise Speed, mph	119
Economical Cruise Speed, mph	119
Range with Standard Fuel, No Reserve	320
Hover Ceiling, IGE, ft	16,565
Hover Ceiling, OGE, ft	15,100
Maximum Rate of Climb, ft/min	1,083
Service Ceiling, ft	17,720
Maximum External Load @ 5,071 lb. External Gross Weight, lbs	2,500

Table 2 - Performance Specifications of the Lama 315B

3.0 STAND DESCRIPTION

The study area consisted of a single 67 acre (estimated) thinning unit which was part of the Ridge Timber Sale on the Rigdon Ranger District of the Willamette National Forest (figure 1 for general vicinity map). Cut trees were marked by the Forest Service. The stand, which was essentially even-aged and approximately 70 years old, had apparently originated as the result of natural regeneration following wildfire. Average slope within the unit was 40% and ranged from 35% to 60%.

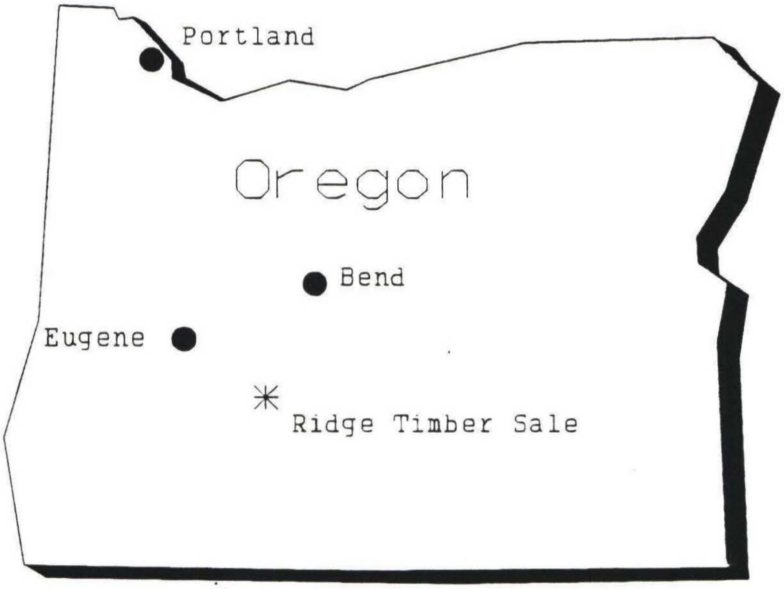


Figure 1 - General Vicinity Map

Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) was the primary species making up roughly 2/3 of the volume on the site. Other major species included grand fir (Abies grandis (Dougl.) Lindl.), Pacific silver fir (Abies amabilis (Dougl.) Forbes), white fir (Abies concolor (Gord. and Glend.) Lindl.), and noble fir (Abies procera (Rehd.)). The unit was located at an elevation of 5000 to 6000 feet and was generally south facing.

According to an initial stand exam and a subsequent cruise, merchantable volume per acre averaged approximately 33 mbf or 69 cunits[1]. The volume designated for removal was approximately 9.8 mbf (21 cunits) per acre. Nearly the entire stand was of merchantable size. About 52 trees per acre were marked for removal from a total of approximately 190 trees per acre. The average diameter at breast height was 14.9 inches for cut trees and 17 inches for leave trees. The average height of the residual stand was estimated to be approximately 100-110 feet. Total stand defect was estimated at about 5.8%.

The silvicultural prescription for this area had called for a single thinning, followed by a regeneration harvest cut in 20 to 30 years. The thinning was meant to reduce stocking and result in increased growth on fewer trees. Trees to be removed were marked from the dead, dying, suppressed, and intermediate tree classes except in those cases where codominants were marked in an effort to release several other codominant trees.

---

[1] *2.09 cunits per mbf based on cruise data*

4.0 YARDING SYSTEMS

4.1 Helicopter Operation

4.1.1 Study Procedure

The unit was logged during the month of October, 1988. Gross production data were kept on site by the company's project manager over the entire harvest period. Appendix A contains a sample sheet showing the type of data collected by the project manager and a summary of the data. The entire volume on the unit was cold-decked on site until yarding was nearly complete. Scaling was done during hauling by a third party scaling bureau.

During yarding, on three separate days, detailed time study data were collected by the researcher. A separate section of this paper discusses data collection methods. Also, results and implications of the data are discussed.

Upon completion of yarding, a damage survey was conducted which utilized twelve 1/2 acre plots. A hand compass and pacing were used to locate plot centers which were laid out on a grid basis. Distance from plot center to plot center was approximately 330 feet. This resulted in all areas of the unit being adequately represented in the sample. Any damage to residual trees which could not be clearly attributed to an activity other than yarding (e.g. falling) was noted.

4.1.2 Yarding Distances and Road Building Requirements

The unit was downhill logged to an existing road (see figure 2). Another road, which had been built to provide access for a cable yarder to the top of the unit, was used only for service vehicles and was not considered essential to the operation. Logs were flown to a landing which had been constructed for another cable unit and was not part of this sale. No additional widening or construction was required for the helicopter's use.

Average yarding distance was approximately 2500 feet. External yarding distance was about 3100 feet and the closest yarding distance was approximately 1900 feet. The unit and road configurations made it impossible for the landing to be situated any closer to the base of the unit. Elevation at the landing was approximately 4800 feet. Elevation at the top of the unit was approximately 6000 feet.

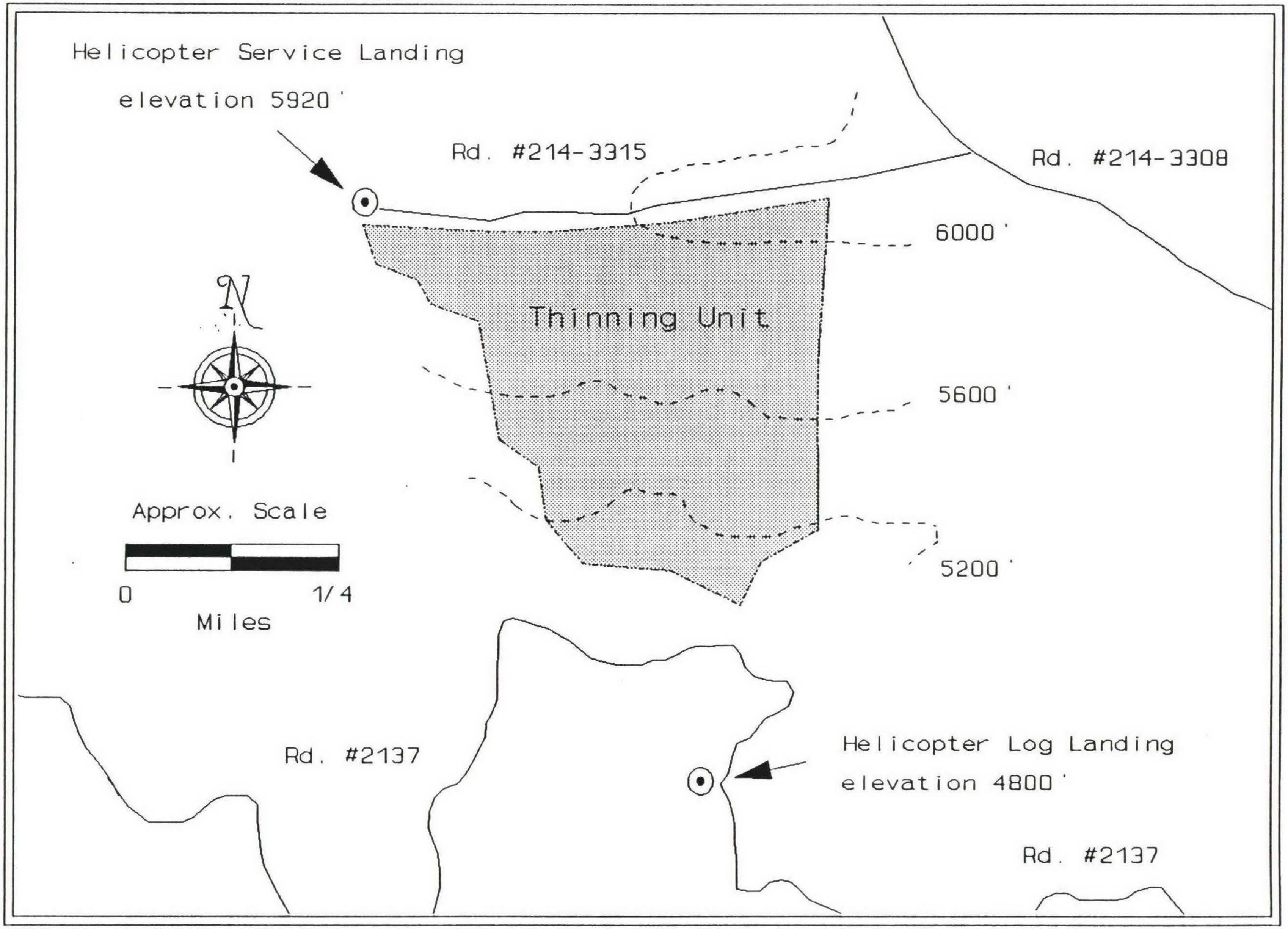

Helicopter Service Landing
elevation 5920'
Rd. #214-3315
Rd. #214-3308
6000'
Thinning Unit
N
5600'
Approx. Scale
0
1/4
Miles
5200'
Rd. #2137
Helicopter Log Landing
elevation 4800'
Rd. #2137

Figure 2 - Unit Configuration for Helicopter Logging

4.1.3 Equipment

In addition to the Lama SA 315B helicopter described earlier, other equipment included a fuel truck, a fuel tank trailer, a mechanics truck with spare parts and tools, and a Caterpillar 966 front end loader.

The fuel tank trailer was utilized in this particular case because the long distance to the nearest source of aviation fuel made it impractical to refill the fuel truck on a regular basis. Other equipment expenses included radios, chokers, fire equipment, and pickups for crew transportation.

4.1.4 Crew

The support crew for the helicopter consisted of 6 to 10 people. All personnel had substantial experience working at their positions. A single pilot and a mechanic were used to fly and service the helicopter. Two people (chasers) worked at the landing bumping knots, wrapping chokers, and taking chokers off of incoming turns. The number of choker setters in the woods varied from two to three people, except for the last day when 4 people set chokers. A project manager supervised the operation and would at times also set chokers if the crew was short for reasons of sickness, etc. The project manager was also responsible for supervision of the falling operations. An additional person was needed to operate a Caterpillar 966 front end loader which was used to remove logs from the landing after the helicopter had completed a turn.

The calculations of crew costs for the operation are first based on a standard crew size used for the operation: 1 project manager, 2 chasers, 3 choker setters, 1 front-end loader operator, 1 mechanic, and 1 pilot. The actual hours and number of people working while the unit was logged are then used to determine a cost which includes delays.

4.2 Hypothetical Cable System

4.2.1 Study Procedure - And Background

The unit was originally planned for cable yarding. The Forest Service Timber Sale Contract required uphill cable yarding with a system capable of intermediate supports. Road construction to the top of the unit was required by the contract in order to provide access for the cable machine.

The helicopter system was approved for use after the timber purchaser had solicited bids for logging the unit. The bid process had resulted in the helicopter bid being 2/3 the cost of the closest cable logging bid. A contract change was requested by the purchaser and approved, with conditions, by the District.

As part of the Forest Service contract preparation, a cable yarding cost appraisal was completed. This hypothetical cable system with updated costs is used as the basis for comparison with the helicopter system. As part of the appraisal process the Forest Service personnel had estimated a production rate. The estimate was based primarily on personal experience of the local equipment and crews and their capabilities and was not analytically derived. This study will use a regression equation developed by Hochrein (1986) to predict what level of production could be achieved by the hypothetical cable system.

An estimate of potential residual tree damage from cable yarding is derived using a regression equation developed by Caccavano (1982).

4.2.2 Yarding Distances and Road Building Requirements

Road construction along the top of the unit had been required as part of the Forest Service contract for anticipated uphill cable logging. The length of this road (see figure 3 , road 3315) was .62 miles. This road was constructed by the purchaser prior to the decision to use a helicopter, which made the road unnecessary. The Forest Service had also anticipated additional small spur roads and landing construction to be necessary for yarder access.

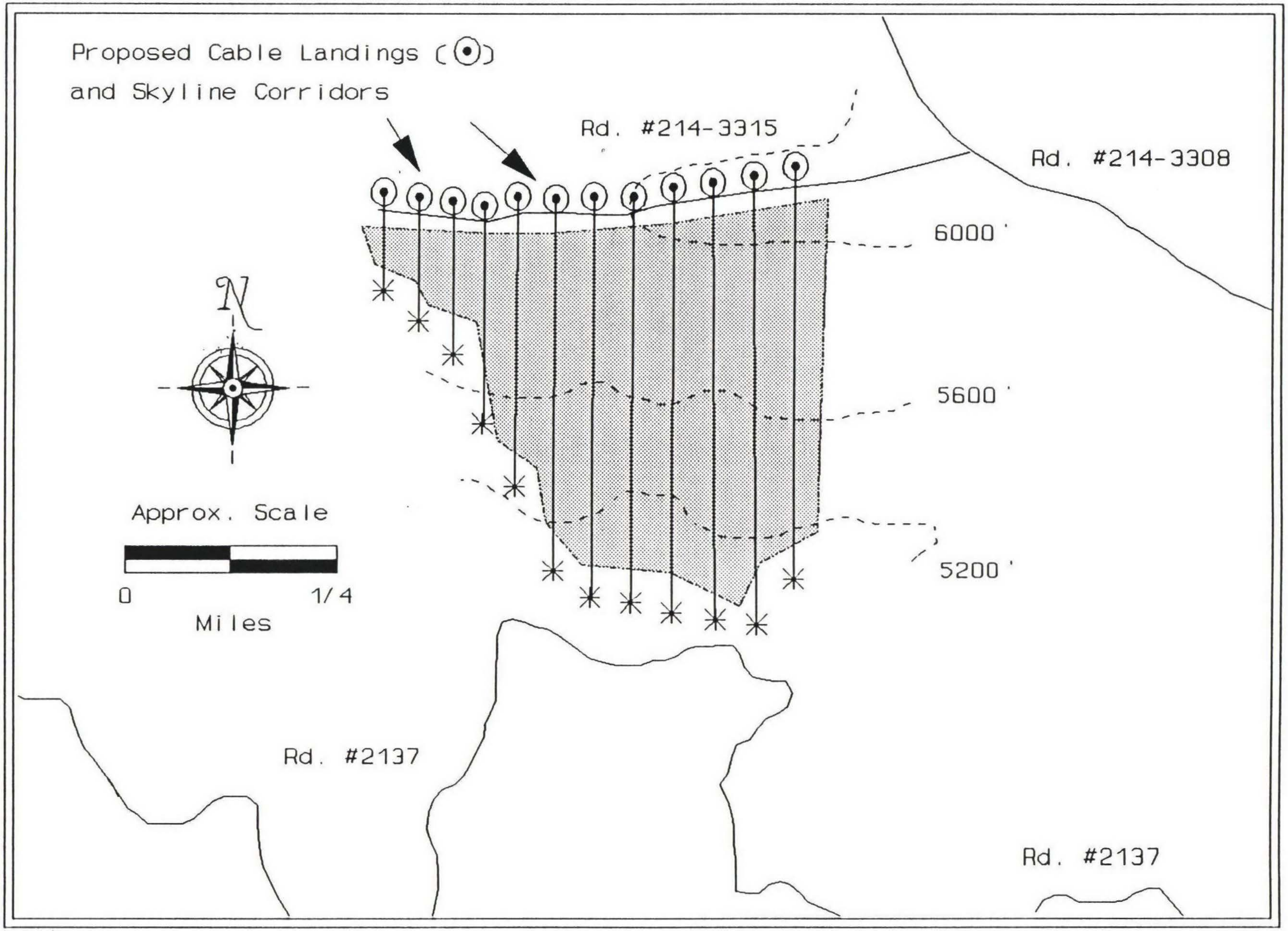

Proposed Cable Landings (⊙)
and Skyline Corridors
Rd. #214-3315
Rd. #214-3308
6000'
5600'
5200'
N
Approx. Scale
0
1/4
Miles
Rd. #2137
Rd. #2137

Figure 3 - Unit Configuration for Cable Yarding

External cable yarding distance for the unit was 2300 feet. Average cable yarding distance was approximately 756 feet. Profile analysis determined that several skyline corridors would require intermediate supports, and several of these corridors needed more than one intermediate support.

4.2.3 Equipment

A Thunderbird TMY 50, SPRM (self propelled, rubber mounted) yarder with a 50 foot tower was the appraised yarder for the unit. The carriage provided for in the appraisal was a Danebo MSP heavy duty carriage with support adapter. Other special equipment required for the intermediate supports was also included.

A landing tractor (a used D6) was the only other significant piece of equipment provided for in the cable yarding appraisal. The tractor was needed in order to keep the landing clear during yarding. Wire rope, chokers, blocks, radios, etc., are also included as expenses in the appraisal.

4.2.4 Crew

The anticipated crew for cable logging operations consisted of six people: 1 hook tender, 1 rigging slinger, 2 choker setters, 1 landing chaser, and a yarder engineer. The landing tractor would be operated by the landing chaser because low production is assumed with the cable yarder.

5.0 RESULTS

5.1 Cost Evaluation

A hourly cost summary for both yarding systems can be found in table 3[2]. The detailed cost analysis for the helicopter and cable systems can be found in Appendices B and C, respectively.

Cost Item	Helicopter System *	Cable System **
Ownership Cost	134.05	70.01
Operating Cost	281.07	40.79
Labor Cost	196.52	124.00
Total Hourly	611.64	234.80
Hourly Cost w/ delays	648.75 ***	

* based on flight hours and including helicopter & crew, 966, crew & mechanics vehicles

** includes yarder & crew, landing cat, crew & mechanics vehicles

*** this figure is adjusted for actual crew hours worked

Table 3 - Hourly Cost Comparison

---

[2] *all costs are in 1988 dollars*

The total cost per flight hour for the helicopter operation using a normal crew size was $611.64. When the cost per flight hour includes the cost of the delays experienced during yarding, the hourly cost equaled $648.75[3]. Average wage figures for typical logging positions in the State of Oregon were used in the calculations (Association of Oregon Loggers, 1988; USDA Forest Service, 1987). Machine cost for the helicopter was calculated using a procedure provided by Aerospatiale for determining hourly costs for the Lama helicopter. This figure includes all costs for a mechanic, including an average cost for unanticipated or unscheduled repair work.

A total anticipated hourly cost of $234.80 for the cable system was calculated. This cost is based on average equipment and crew costs (USDA Forest Service, 1987).

5.1.1 Cost of Delays

The cost of delays is handled differently for the cable system and the helicopter operation. When using the hourly cost for the cable system in conjunction with a production estimate a more standard approach would be used. An effective hour determination would be made which would reduce the efficiency of the operation. In this way the added costs of delays can be accounted for.

---

[3] - *all equipment costs include an opportunity cost @ 12.5%*

It is more common for aircraft ownership, operating, and labor costs to be tied directly to actual flight hours. When the helicopter is on the ground it is assumed that no costs are incurred other then the labor costs of the crew as they wait. Data from the gross production study was used to determine the actual crew costs per flight hour and are the basis for the additional cost of delays. On short days, crew time was charged only for the hours actually worked, a common practice for helicopter operations.

The hourly cost with delays for the helicopter operation takes into account delays for refueling, maintenance, and travel time. If this cost is used with a production estimate no reduction in efficiency would be needed, i.e. the effective hour equals 60 minutes.

5.2 Production

5.2.1 Helicopter

The helicopter system yarded an average of 3.62 MBF[4] per flight hour (7.57 cunits/hour) during actual operations. This figure is based on the total flight hours (106 hours) for the helicopter and the scale information provided by the Rigdon Ranger District office.

5.2.2 Cable System

A regression equation developed by Hochrein (1986) predicts that the cable system will have a production rate of 1.47 mbf/hour (3.10 cunits/hour), net scale. Appendix E shows how this figure was derived.

As stated previously a review of currently available production studies for cable thinning systems indicated none with an average yarding distance of greater than 600 feet. In addition, very few had adequately sampled a system with intermediate supports. For Hochrein's study the average yarding distance was 516 feet and only a single span system was used. Except for these differences and somewhat smaller timber the study conditions used to derive Hochrein's equation are reasonably close to those for the Ridge thinning unit. Although some of the differences may contribute to either an overestimate or underestimate of production, for the purposes of this report it is assumed that the equation provides a reasonable estimate of production. Appendix E provides a chart with a comparison of the conditions for both studies and further discussion on the use of the equation.

---

[4] *net scale - net to gross ratio of .944*

5.3 Comparison of Cost/mbf for Each System

The analysis indicates that the helicopter logging system was able to yard the unit for an average of $179.21/mbf or $85.74/cunit. It is estimated that the cable system would have cost $159.73/mbf or $75.74/cunit for the yarding. The total cost for the road and landing construction required for the cable system was estimated at $21,147. Because the road does not provide access to other units within the area, the entire cost must be amortized over the volume removed from this unit. This would have resulted in an additional $55.21/mbf or $26.42/cunit (383 mbf total volume removed) in costs for cable logging.

Since the production capability of the cable system is only an estimate, back-calculation can be used to determine what level of production is necessary for the cable system to equal the cost of the helicopter system. The necessary cable production for the yarding systems to have equal cost is 1.31 mbf/hour (2.74 cunits/hour), or a 11% decrease in the predicted production. If road and landing costs are taken into account, the cable system would have to produce 1.89 mbf/hour (3.95 cunits/hour), or a 29% increase over the predicted production.

5.4 Residual Stand Damage

5.4.1 Helicopter System

As mentioned previously, a post yarding survey was taken using twelve 1/2 acre plots to determine the amount of damage to the residual stand. The survey indicated no damage to the residual stand which could be attributed to the yarding operations. Only five trees had minor damage, and this damage was clearly the result of felling operations. It should also be mentioned that the only damage observed outside of the sample plots were a couple of tops which were broken out and some limbs that had been broken.

5.4.2 Cable System

Current research (Burditt, 1982; Caccavano, 1982) has indicated several variables which can increase damage to the residual stand during thinning operations. Stand characteristics which increase susceptibility to damage include steeper slopes, presence of true fir or hemlock, and higher volumes for both cut and leave trees. The use of larger yarders (the T-bird TMY 50 is considered a large thinning yarder) may also result in higher amounts of damage to residual stands.

Predicting the actual stand damage that would have occurred if the stand had been cable yarded is difficult. In a study conducted by Caccavano (1982), a regression equation was developed which predicts the square feet of scar area per acre resulting from cable thinning operations. The equation and the resulting prediction for stand damage using the stand characteristics for this study area are shown in figure 4.

Of the 68 skyline corridors that Caccavano examined in his study (taken from 10 different thinning units), only three corridors had damage levels higher than the 44.6 square feet of scar area per acre predicted for this study area. The corridor with the most damage in Caccavano's study had 64.4 square feet of scar area per acre. It was his conclusion that this level of damage would probably have a significant detrimental effect on future stand value.

Most of the thinned stands from which Caccavano derived his equation had conditions which would result in lower damage (e.g. gentler slopes, lower amounts of true fir species, and smaller yarders). The potentially dramatic effect of time of year on damage levels is also not taken into account by the equation. Because of this, the actual amount of damage which would have occurred for this study area may have been substantially different than the amount predicted by the regression equation.

Regression Equation

$$\text{Scar Area} = -23.6120 + 0.659223*WH + 0.0221402*VOLREM -7.84103*S$$

Independent Variables

Scar Area = square feet per acre
WH = % western hemlock or non-Douglas fir species in the stand
VOLREM = volume removed in cubic feet per acre
S = type of system, 0 if conventional, 1 if prebunched & swung

Results for this Study

Predicted Scar Area = 44.6 ft^2/acre

where WH = 33% VOLREM = 2098 S = 0

Figure 4 - Regression Analysis of Potential Residual Damage

5.5 Detailed Time Study

5.5.1 Study Procedure

A detailed time study was conducted over a period of roughly 11 hours of operations and 296 turns using a continuous timing method with a stopwatch (see Appendix D for more detail). Both productive and non-productive times were taken during the study.

Elements of the yarding cycle which were timed include outhaul, hook, inhaul, unhook, and time spent picking up chokers. A description of these turn time elements is included in Appendix D. Time picking up chokers was the only in-flight delay which could be clearly identified. It was found to be insignificant and was dropped from the analysis. Delays for fueling and maintenance are taken into account by the cost per flight hour as explained in section 5.1.1. Independent variables which were measured include the number of logs per turn and the weight of each turn. It was also noted whether chokers were being delivered during the turn cycle. Choker delivery was necessary when a choker setter had sent in all of his chokers with turns and required a resupply. This activity would take added time because the pilot had to position the new chokers in the next area to be yarded. The approximate location of the origin of each turn within the unit was estimated. A contour map was later used to estimate yarding distances.

5.5.2 Statistics

Times

Five different choker setting locations were sampled during the time study. The weighted average yarding distance for these sampled locations was equal to 2653 feet (not the unit average of 2500 feet). The unit was homogenous enough so that average hook and unhook times based on these data probably closely reflect the averages for the unit.

A statistical summary of the times for outhaul, hook, inhaul, and unhook can be found in Table 4. A component chart showing the relative amounts of each element and the source of variability for total turn times is shown in Figure 5.

Statistical Summary of Data Taken During Detailed Time Study

	Turn Time Elements (seconds)						Independent Variables		
Variable:	Yardout	Hook	Yardin	Unhook	Yardout+ Yardin	Total Time	Pieces	Weight (lbs.)	Yarding Dist(ft)
Sample size	231	236	237	235	229	225	240	269	240
Average	26.55	60.60	28.59	9.08	55.11	124.67	1.43	1780	2653
Median	25	54	28	9	54	118	1	1700	2700
Variance	21.89	616.11	20.36	6.93	59.22	591.57	0.36	1973	52797
Standard dev.	4.68	24.82	4.51	2.63	7.70	24.32	0.60	444	230
Standard error	0.31	1.62	0.29	0.17	0.51	1.62	0.04	27	14.83
Minimum	16	20	15	3	36	90	1	900	2300
Maximum	43	180	42	21	74	261	3	2900	3100
Range	27	160	27	18	38	171	2	2000	800

Table 4 - Statistics Summary

Component Chart of Turn Time Elements

shows the relative amount of time spent in each activity and the source of time variability

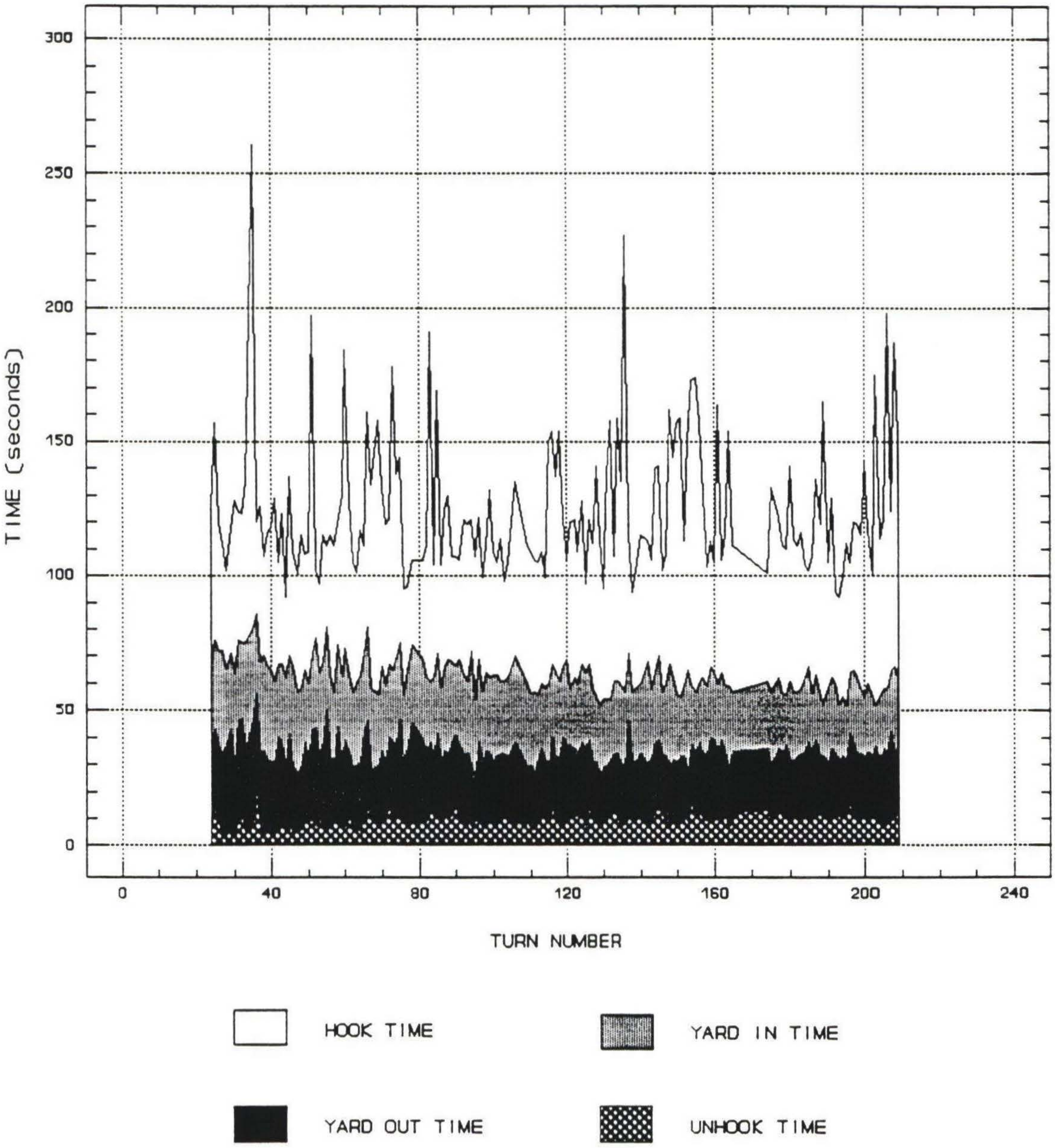


Figure 5 - Component Chart of Turn Time Elements

Independent Variables

Logs per Turn

The average turn consisted of 1.43 logs with a standard deviation of .60. The largest turn was only 3 logs in size. Figure 6 shows the relative distribution of turn sizes based on logs per turn.

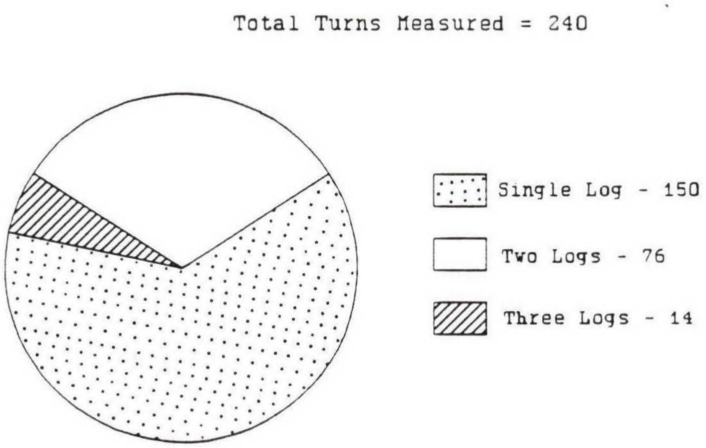


Figure 6 - Number of Logs per Turn

Weight per Turn

The helicopter has a device for measuring the weight of external loads. The average weight per turn was 1780 pounds (71% of lifting capacity) with a standard deviation of 444 lbs. The smallest turn size was 900 pounds and the largest turn size was 2900 pounds. Figure 7 shows the relative distribution of turn sizes based on weight.

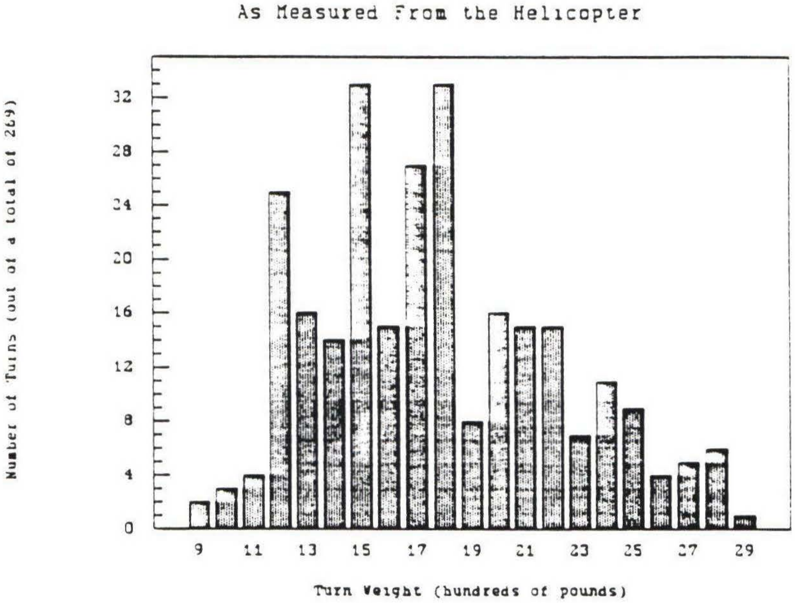


Figure 7 - Distribution of Turn Weights

5.5.3 Hook Time Regression

Multiple linear regression was used to find a relationship between turn weight, choker delivery (a zero/one variable), and hook time for the turns. The resulting regression equation had a R-squared value of 22%. Both variables and the constant were significant at the .001 level. The equation is as follows:

Hook time = 21.393274 + 2.052894 Wght + 22.658839 Chokers

Hook time (seconds) = see Appendix D for description
Wght = weight of turn in hundreds of pounds
Chokers = are chokers being delivered during the turn cycle, 1 = yes, 0 = no.

Valid over the following range of values:
Weight - from 900 to 2900 pounds

Chokers were delivered an average of 1 in 10 turns. As mentioned, the average weight of the turns was 1780 pounds. The large number of single log turns points out the fact that most piece sizes did not allow for the choker setters to vary the turn weights. The ability to optimize total turn productivity depends both on the ability to manipulate turn size and turn speed by selectively choosing log combinations. If the choker setters had been able to average 2,000 pounds during the study, the equation predicts that this would have added 3.6% to the total turn time from longer hook times (increase in hook time/average total turn time). However, the increase in production because of increased average turn sizes would have been 12.3% (2000/1780). The end result would have been a net increase in production of 8.7%.

The ability to optimize the size of each turn may be affected in several ways. Better bucking strategies can provide a broader mix of log sizes making an optimal turn size possible. Hooking techniques should take advantage of the log sizes available to optimize turn size and improve production. In either case it is necessary for the cutters and choker setters to know ahead of time what constitutes an optimal turn size. If bucking practices are pre-determined by market considerations the structure of the stand will be the primary factor controlling average turn size. Stands with more variation in the size of cut trees may have a positive effect on the overall productivity of the helicopter operation.

5.5.4 Turn Time Regression

5.5.4.1 Predicting Production Based on Yarding Distance

The time study data were used to determine a relationship between yarding distance and total haul time (inhaul plus outhaul). The resulting equation (haultime (sec) = 10.264 + .0168951*distance (ft)) had a R-squared value of 26% and both the constant and variable were significant at a level of .05. The range of values over which the equation is valid is 2300′ - 3100′. Appendix D gives further information on the regression analysis used to derive this relationship.

A relationship between yarding distance and total turn time can be derived by adding to this equation the average times (seconds) for hooking and unhooking the turns. Hourly production can then be estimated based on the average turn size (see Appendix D for the method used to adjust turn weights to board foot measurements).

Figure 8 shows the predicted production rates per hour based on yarding distance. As can be seen, the predicted rate for the unit average yarding distance (2500′) is approximately 3.68 mbf/flight-hour which closely matches the actual experienced average production of 3.62 mbf/flight-hour (using gross log scale, the actual production for the helicopter was 3.83 mbf/hour).

Unfortunately, the range of yarding distances sampled by this study is quite narrow (2300 to 3100 feet). Any attempt to extrapolate the results of the equation outside of the sampled range may result in unacceptable error. Predicting values outside of the sampled range would also be contrary to normally accepted statistical methods.

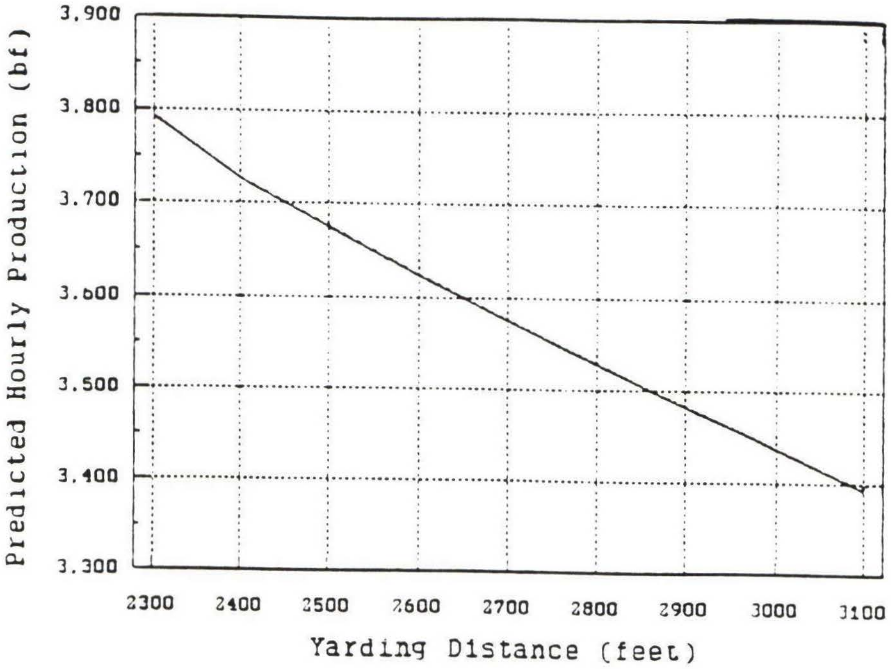


Figure 8 - Predicted Hourly Production

5.5.4.2 Composite Total Turn Time Equation

By combining the two separate regression equations for hook time and haultime, and adding to them the average unhook time, a composite regression equation for total turn time can be obtained. The resulting equation is as follows:

$$\text{Total Turn Time} = 40.737274 + 0.0168951 * \text{Distance} + 2.052894 * \text{Weight} + 22.658839 * \text{Chokers}$$

Total Turn Time = delay free turn time in seconds
Distance = slope Yarding Distance in feet
Weight = turn weight in hundreds of pounds
Chokers = are chokers being delivered during the turn cycle, 1 = yes, 0 = no

Valid over the following range of values:
Distance - from 2300′ to 3100′
Weight - from 900 to 2900 pounds

The values for total turn time as predicted by this equation were checked against the actual values. A R-squared value of 26% was calculated using the formula, 1 - SSResid/SSTo (see Appendix D). This figure, 26%, indicates that only a small percentage of the total variability of total turn times is accounted for by this equation. I would not recommend that this equation be used to predict turn times for other logging sites. The equation is presented here only as a topic for discussion and review.

6.0 DISCUSSION OF RESULTS

6.1 Evaluation of the Overall Economic Feasibility

6.1.1 Single Entry Logging Costs

An estimate of the total logging costs which were incurred during the removal of this timber can be found in Table 5. The cost for felling and bucking is based on the actual contracted cost incurred by Rocky Mountain Helicopters for this sale. The costs for loading and hauling are estimates based on additional cost evaluations. The cost for yarding is based on the gross production data for the helicopter operation discussed previously and includes delays, travel time, and move-in costs.

	Production (mbf/hr)	Ownership ($/mbf)	Operating ($/mbf)	Labor ($/mbf)	Total Cost ($/mbf)
FALL	# 1.00	$ 0.18	$ 0.41	$ 26.40	$ 27.00
SKID	# 3.62	$ 37.03	$ 77.64	$ 64.53	$ 179.21
LOAD	# 4.20	$ 8.36	$ 6.25	$ 4.80	$ 19.41
TRAN	# 1.56	$ 12.11	$ 9.51	$ 10.41	$ 32.03
ROAD		$ 0.00	$ 0.00	$ 0.00	$ 0.00
Totals		$ 56.68	$ 93.81	$ 106.14	$ 257.65

Table 5 - Total Logging Cost Summary

Pond values for smaller diameter logs at the time of this study generally range from \$300/mbf for true fir to \$370/mbf for Douglas fir (Garver, 1989). The average log value, taking species mix into account, would then be \$345.88/mbf (66% Douglas fir and 34% true fir). This leaves approximately \$88.23/mbf of margin for additional costs, e.g. stumpage or sale preparation, and for profit.

In general, the cost to prepare a thinning sale is greater than the costs for clearcut harvest operations. Depending on the landowner's requirements, varying amounts of preparation including stand exams, marking, and cruising are necessary. The costs associated with hauling, and felling and bucking vary according to sale location and the local job market. In addition, pond values may be more or less depending on the location of a given sale and current market conditions.

6.1.2 Other Cable Production and Cost Estimates

It should be mentioned that the Forest Service production estimate for the cable system was .75 mbf/hour (1.57 cunits/hour). This would have resulted in a cost of \$313/mbf (\$150/cunit). Prior to acceptance of the bid from Rocky Mountain Helicopters the timber purchaser had also received two bids from skyline loggers. The nearest cable bid was 50% greater than the bid for helicopter yarding.

These significantly greater cost estimates may indicate that local skyline loggers are experiencing reduced productivity when implementing complex multispan systems. Hochrein's equation was based on a relatively short, single span system. The use of his equation is only valid if skyline loggers can be found that can implement a complex multispan system without reducing production.

6.2 Implications for Final Harvest Entry

6.2.1 Future Stand Value and Growth

Previous research (Tappeiner, 1982; Reukema, 1977) has shown that commercial thinnings can provide greater overall revenue and an increase in total wood volume. Damaging the residual stand makes the economics of thinning much less clear since it can result in a stand with lower growth and future value. The helicopter system appears to produce essentially no stand damage. Cable thinning can produce substantial damage and in the case of this stand could have resulted in an negative economic impact for the long term.

6.2.2 Value of Postponing Road Construction Costs

This study area would have been particularly difficult to cable yard because of the need for intermediate supports, the long skidding distances, and the amount of volume both removed and left. In a cable thinning operation with shorter skidding distances the anticipated production would have been greater. This could have resulted in the overall cost of cable yarding and roading being lower than the helicopter yarding costs.

A justification for proceeding with the cable system in spite of the higher total cost for roading and yarding might be that the road facility would pay for itself in the future when the unit is eventually clearcut harvested using a large cable system. However, it should be recognized that there is an opportunity cost associated with needlessly spending dollars on road construction at this time.

Obviously, in other areas the costs for cable yarding, helicopter yarding, and road building could all be quite different. Where road costs are low, or no construction is needed, it appears that skyline logging would in most instances be the most economical. The road which was built for cable logging this study area was a minimum standard, native surface road, with a per mile cost of only $25,323. In cases where road costs are much higher than this the most economical option for a land manager may be to forego road building until final harvest and commercial thin by helicopter.

6.3 Implications for Multiple Entries

By choosing to utilize a helicopter system for thinning at this time the land manager would not be limiting future options for management of the stand. In fact, the opposite is true. As mentioned, the road building requirements for final harvest could be accomplished at the time of final harvest if at that time the economics still justified removal by cable system. The subsequent thinnings could be accomplished by whatever yarding system is the most economical at the time.

By building the road at this time, the manager has actually taken away his option of leaving the area unroaded. While in many cases having road access to an area is desirable for fire management, etc. there are also negative aspects to road building. Taking land out of production and providing unwanted access into sensitive wildlife areas would be a couple of examples of possible negative consequences associated with road building. Rehabilitation of a road bed is expensive and road closures to protect wildlife can be ineffective. The land manager may therefore have to live with these consequences for quite some time.

6.4 Production and Cost at Shorter Yarding Distances

Making predictions for productivity or cost outside the range of sampled yarding distances (2300′-3100′) is not usually considered an acceptable practice. However, several arguments can be made why the relationship between total haul time and yarding distance may hold well below the sampled range for this type of system. The confidence limits for mean values of haul time within the sampling range were very narrow, partially because of the large number of turns sampled. Also, the linear relationship between yarding distance and haul time should not change until the turn around times decreased to the point that the choker setters would be unable to keep up. The cost of adding an additional choker setter to help alleviate this problem would add less than $4 to the total cost per mbf. It was also observed that the helicopter generally reaches full speed within seconds of leaving the landing or the hook site and will vary that speed little during the trip to and from the landing.

Figure 9 shows projected yarding costs for yarding distances outside of the range sampled. If the relationship between yarding distance and haul time holds for these shorter distances it appears that the cost per mbf could be as low as $132 at a yarding distance of 500 feet. The projected costs are presented here for discussion only and should not be used as a method for predicting costs or production.

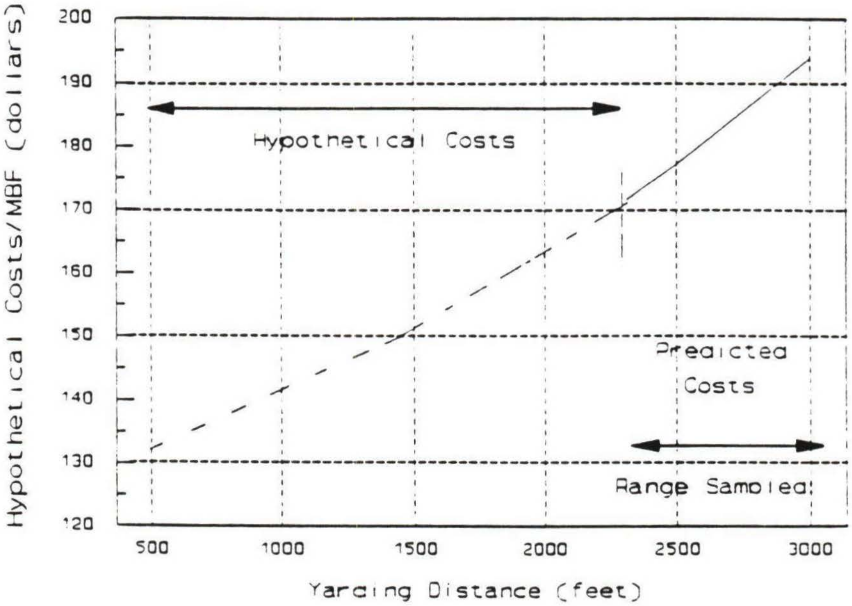


Figure 9 - Hypothetical Costs per MBF

7.0 CONCLUSIONS

This was a particularly difficult logging situation for the helicopter system. The height and density of the residual stand required extensive maneuvering by the pilot resulting in some very long hook times. In addition, the size of the logs made it difficult for the choker setters to adjust turn weights in order to decrease hook times or optimize average turn weight. Average yarding distance was extremely long since the local road system did not allow for a landing at the base of the unit. Despite these difficulties the Lama was apparently able to yard the unit at a price which would allow for a reasonable profit in today's market.

The hypothetical cable system used for comparison would also have been a difficult logging situation. It is however, not unlike many situations which might face forest land managers in coming years. The helicopter appears to be a reasonably good alternative in areas where the cost of skyline logging is unusually high or expensive roads are needed for access.

The complete lack of damage to the residual stand during this study was particularly encouraging for several reasons. The study area had nearly all of the characteristics which tend to increase the chances for residual stand damage. Both Forest Service personnel and the timber purchaser involved in the project mentioned that substantial damage would have resulted if a cable system had been used. In older stands, such as this one, where the economic benefits of thinning may be questionable, land managers may choose to forgo thinning if substantial damage could result. The helicopter provides an alternative method which protects the residual stand and helps to maximize the potential silvicultural benefits of thinning.

7.1 Future Research Possibilities

It appears that the helicopter system could very possibly compete with even smaller yarders in thinnings with average yarding distances of 500 feet or greater. Although the use of these craft for logging is limited (only 3 are logging at this time) the production capability of a single Lama yarding at average distances of 500 feet could be several times that of more conventional cable systems. Further research into the potential use of small helicopters for thinning stands with shorter yarding distances, smaller trees, and more open residual stands might very well indicate that they are a economically viable method for many small wood harvesting situations.

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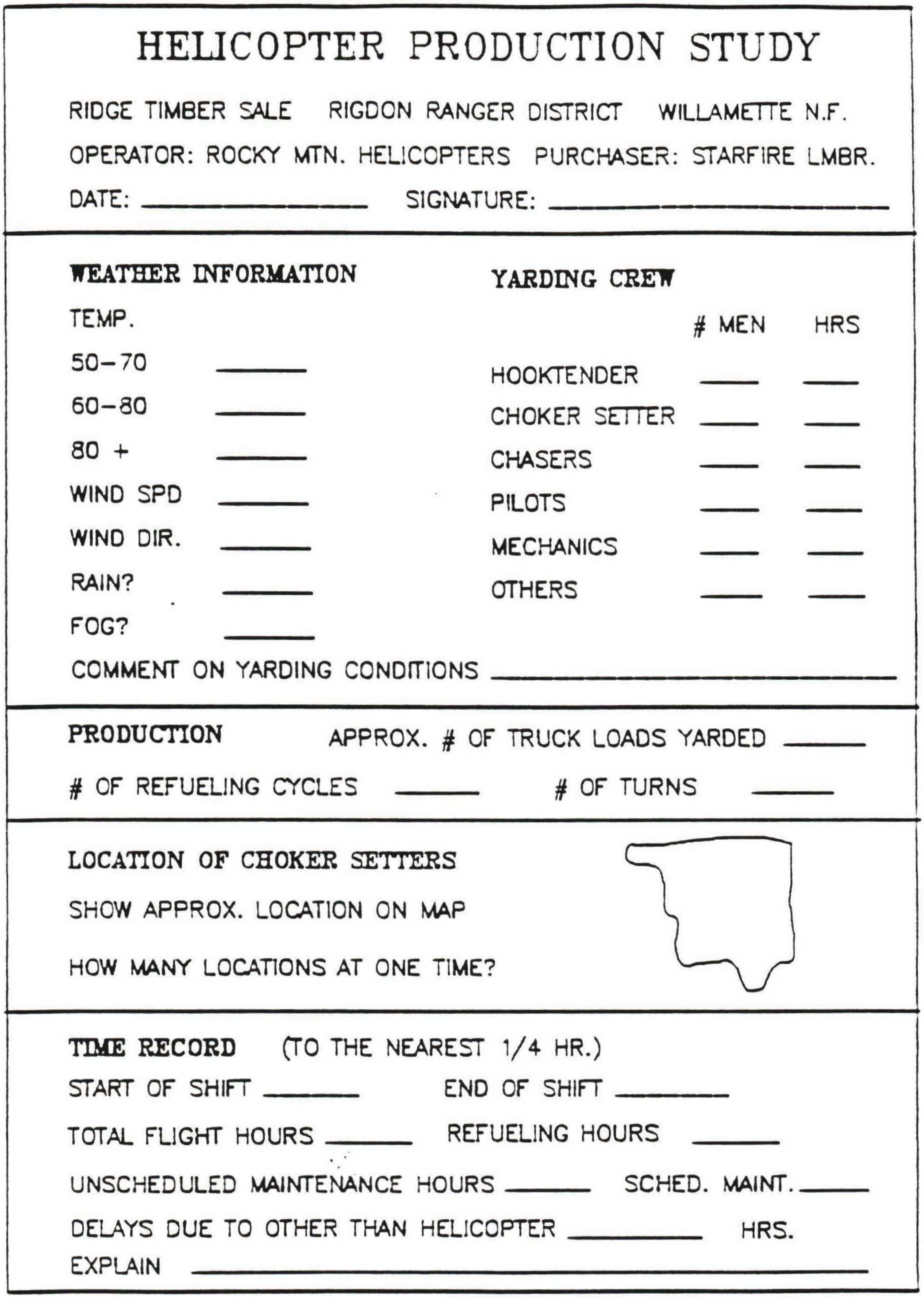
Appendix A

Gross Production Records

The following pages give more detailed information regarding the information gathered during the gross production portion of this study. The project manager for Rocky Mountain Helicopters kept daily records of times, estimated production, and yarding conditions, on forms which were provided for his use. Figure A1 shows the form which was used. Table A1 gives a summary of the information which was collected.

The scale information was obtained from Forest Service statements showing the results of a third party scaling of the timber removed from the unit. A summary of this information is provided in table A2.



HELICOPTER PRODUCTION STUDY

RIDGE TIMBER SALE RIGDON RANGER DISTRICT WILLAMETTE N.F.

OPERATOR: ROCKY MTN. HELICOPTERS PURCHASER: STARFIRE LMBR.

DATE: ______ SIGNATURE: ______

WEATHER INFORMATION

TEMP.

50–70 ______

60–80 ______

80 + ______

WIND SPD ______

WIND DIR. ______

RAIN? ______

FOG? ______

YARDING CREW

	# MEN	HRS
HOOKTENDER	____	____
CHOKER SETTER	____	____
CHASERS	____	____
PILOTS	____	____
MECHANICS	____	____
OTHERS	____	____

COMMENT ON YARDING CONDITIONS ______

PRODUCTION APPROX. # OF TRUCK LOADS YARDED ______

OF REFUELING CYCLES ______ # OF TURNS ______

LOCATION OF CHOKER SETTERS

SHOW APPROX. LOCATION ON MAP

HOW MANY LOCATIONS AT ONE TIME?

TIME RECORD (TO THE NEAREST 1/4 HR.)

START OF SHIFT ______ END OF SHIFT ______

TOTAL FLIGHT HOURS ______ REFUELING HOURS ______

UNSCHEDULED MAINTENANCE HOURS ______ SCHED. MAINT. ______

DELAYS DUE TO OTHER THAN HELICOPTER ______ HRS.

EXPLAIN ______

Figure A1 – Example of the Gross Production Form

GROSS PRODUCTION DATA

RIDGE TIMBER SALE - RIDGON R.D., WILLAMETTE N.F.

	HELICOPTER HOURS					PERSONNEL HOURS			ESTIMATED PROD.	
DATE	TOTAL SHIFT HOURS	IN FLIGHT HOURS	FUELING MIN.	SCHED. MAINT. (MIN)*	UNSCHED. MAINT. (MIN)*	CHOKER SETTERS	CHASERS HOURS	PROJECT MANAGER	TURNS	EST. TRK. LOADS
29-Sep-88	9	7	50	15	0	27	18	9	220	7
30-Sep-88	8	5.5	40	20	40	24	16	8	150	5
01-Oct-88	10	8	60	20	0	20	20	10	210	8
02-Oct-88	1	1	0	0	REP. TRAN.	2	2	0	32	1
03-Oct-88										
04-Oct-88	6	6	40	0	0	12	6	6	168	6
05-Oct-88	9	8	60	20	0	18	9	9	240	8
06-Oct-88	7	6	50	10	0	14	7	7	210	7
07-Oct-88	8	6.5	60	20	0	24	16	8	288	8
08-Oct-88										
09-Oct-88										
10-Oct-88	8	6.5	60	20	0	8	16	8	280	7
11-Oct-88	9.5	8	60	20	0	27	18	9	296	7
12-Oct-88	9.5	8	60	20	0	27	18	9	320	8
13-Oct-88	9.5	8	60	20	0	27	18	9	300	8
14-Oct-88					REP. ROTOR					
15-Oct-88										
16-Oct-88	5	4.5	30	0	0	13.5	9	4.5	150	5
17-Oct-88										
18-Oct-88	6.5	5	30	0	0	19.5	13	0	200	5
19-Oct-88	9.5	8	60	20	0	16	16	8	340	8
20-Oct-88	9.5	8	60	20	0	24	16	8	330	8
21-Oct-88	2	1.75	15	0	0	6	4	2	70	
TOTAL			795	225	40	309	222	114.5	3804	106
TOTAL HOURS	127	105.8	13.25	3.75	0.67	309	222	86**		

* Maintenance hours shown are only those hours which took place during scheduled shifts and resulted in delays for the support crew.

** Project Manager was estimated to spend about 3/4 of his time working with the yarding operation. Other time was spent supervising falling operations or on other jobs.

Table A1 - Gross Production Summary

Table A2 - Summary of Scale Records

Summary of Scale Records

Species	# of logs	Gross Vol.	Net Vol.
Doug. fir	3008		250.86
	3165	262.03	
Grand fir	470		39.46
	495	41.39	
Pacific silver fir	274		13.43
	292	14.02	
White fir	339		40.81
	357	43.43	
Noble fir	237		30.30
	261	35.61	
Hemlock & Others	78		7.92
	78	8.94	
Totals	4648 (gross)	405.42	382.78

note: the difference in # of logs for each species represents the number of cull logs hauled and scaled.

Appendix B

Detailed Cost Analysis - Helicopter System

Table B1 shows the cost summary from PACE for the helicopter, pilot, mechanic, and standard crew.

Table B1 - Cost Summary for Helicopter, pilot, mechanic, and crew

```
--------------------- Summary -------------------------

** Lama SA 315B Helicopter w/pilot, mech. and crew incl. **

Ownership
     Depreciable value:                $      376.715.00
     Equipment depreciation:           $       53,816.43 / Year
     Interest expense:                 $       55,885.72 / Year
     Taxes, lic., insur. & storage:    $       63,683.73 / Year
     Annual ownership cost:            $      173,385.88 / Year
     Ownership cost (Subtotal):        $          108.37 / Hour
Machine operating
     Repairs and maintenance:          $          167.67 / Hour
     Fuel and oil:                     $           92.70 / Hour
     Lines and rigging:                $            0.53 / Hour
     Tires or tracks:                  $            0.00 / Hour
     Equip. oper. cost (Subtotal):     $          260.91 / Hour
Labor
     Direct labor cost:                $          151.28 / Hour
     Supervision and overhead:         $           22.69 / Hour
     Labor cost (Subtotal):            $          173.98 / Hour

OWNERSHIP COST                         $          108.37 / Hour
OPERATING COST                         $          260.91 / Hour
LABOR COST                             $          173.98 / Hour

Machine rate (Owner.+ Oper.+ Labor)    $          543.25 / Hour
```

Ownership Costs

The ownership cost is based on three items: depreciation, interest expense, and a category for taxes, license, insurance, and storage. The number of hours worked per year determines how the hourly costs will be calculated given the annual costs. I assumed that this helicopter is used an average of 1600 hours per year. This is a higher figure than that used in other helicopter logging studies

(Dykstra, 1976). I used this figure based on my personal observations of the company's use of these helicopters over a period of 3 years. Also, these helicopters tend to be used for a wider range of applications than some of the larger craft. Often times there is no "down season" because during winter in the Northwest they will sometimes move to the south and log in the swamps of Louisiana.

Depreciation

An aircraft is different than other types of equipment in that it is never allowed to deteriorate significantly during its useful life. For safety reasons almost every part of the Lama helicopter is replaced after a set number of hours. The helicopter used in this study was 11 years old and yet was probably every bit as reliable as when it was new. For this reason a depreciation expense might not be appropriate. However, in order to be more consistent with past work and appraisal methods I have included a depreciation expense. The cost calculation is fairly standard for large equipment (7 year life to a salvage value of 20%). The initial cost used in this depreciation ($470,894) is the hull value of the craft ($680,000) minus the cost of the engine, rotors, tail-rotors, and "A" frame assembly. These items, because of their large expense and short lives relative to the useful life of the helicopter, are depreciated as a direct hourly cost (see Aerospatiale direct operating cost summary).

Interest Expense

This cost is essentially the financing cost or opportunity cost associated with owning the aircraft. I used the entire $680,000 hull value to calculate a mean annual investment from which this cost is determined. An interest rate of 12.5% was used. This figure is in the middle of the range commonly used for logging equipment of similar value.

Taxes, License, Insurance, and Storage

The major cost item here is insurance. From a phone conversation with the owner of the craft it was determined that insurance cost 8% of the hull value ($680,000) annually. This may or may not be an average figure for the industry. The other items in this category were considered to cost 3% of the hull value annually.

Table B2 gives the cost calculations for ownership cost of the helicopter.

Table B2 - Equipment Ownership Cost for Helicopter

Equipment Ownership Costs

Total Hull Value (used for int. exp.)	$	680,000.00
Minus limited life parts	$	209,106.00
Beginning Value to be Used for Deprec.	$	470,894.00
Minus residual (salvage) value	$	94,179.00
Life of equipment (Years)	#	7.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	8.00
Interest Expense	%	12.50
Percent of average annual investment for: Taxes, License, Insurance, and Storage	%	11.00
Depreciable value:	$	376,715.00
Equipment depreciation:	$	53,816.43
Average annual investment:	$	309,444.72
Interest expense:	$	55,885.72
Taxes, license, insurance and storage:	$	63,683.73
Annual ownership cost:	$	173,385.88
Annual utilization (Hours per year):	#	1,600.00
Ownership cost (Dollars per hour):	$	108.37

Equipment Operating Costs

The direct operating costs for the helicopter were taken from the Aerospatiale Helicopter Corporation's "Direct Operating Cost Summary". The figures are based on an average observed cost for operating Lama helicopters. The data was collected from Aerospatiale operators, service stations, and overhaul facilities. Obviously, the costs incurred for an individual type of use may vary from these averages. The only adjustment I made was for an increased fuel use over the average figure. Rocky Mountain Helicopters personnel informed me that fuel use averaged 60 gallons per hour for their logging operations which is 10 gallons more than the figure given in the cost summary guide.

Table B3 gives the cost calculation for direct operating costs for the helicopter.

Table B3 - Direct Operating Costs for the Helicopter

Equipment Operating Costs		
Hourly cost to operate based on summary		167.67
Fuel amount (Gallons per hour)	#	60.00
Fuel cost (Per gallon)	$	1.50
Percent of fuel consump. for lubricants	%	3.00
Cost of oil and lubricants (Per gallon)	$	1.50
Cost of lines	$	820.00
Estimated life of lines (Hours)	#	2,000.00
Cost of rigging	$	1,000.00
Estimated life of rigging (Hours)	#	8,000.00
Repairs and maintenance:	$	167.67
Fuel:	$	90.00
Oil and lubricants:	$	2.70
Lines:	$	0.41
Rigging:	$	0.13
Equipment operating cost (Subtotal):	$	260.91

Labor Costs

The same appraisal guide was used for determining the labor costs for both the helicopter and the cable operation. The Siuslaw National Forest's Appraisal Handbook was used. This handbook uses average regional costs for logging positions. The positions of chaser, choker setter, and hooktender were used for the helicopter support crew costs. The pilot's cost is an estimate based on information provided by Rocky Mtn. Helicopters. The cost for a mechanic is included in the direct operating costs provided by the Aerospatiale Cost Summary and are not separated out in this labor cost portion.

The costs shown in table B4 are for a standard support crew for the helicopter operation. The costs shown in table B5 show the result of calculations using the actual hours worked by the crew (includes delays). These actual hours were taken from the gross data summary found in Appendix A. In addition a travel time of 2 hours per day was included in the gross labor cost calculations.

Table B4 - Labor cost for a standard helicopter crew

```
                     Labor Cost

  Base wage for 1st crew position (Pilot)     $    35.00
  Base wage for 2nd crew position (Chaser)    $    12.02
  Base wage for 3rd crew position (Chaser)    $    12.02
  Base wage for 4th position   (Choker-set)   $    11.81
  Base wage for 5th position   (Choker-set)   $    11.81
  Base wage for 6th position   (Choker-set)   $    11.81
  Base wage for 7th position   (Hook-tend)    $    13.60
  Fringe benefits                             %    40.00
  Travel time per day (Hours)                 #     0.00
  Operating time per day (Hours)              #     8.00
  Percent of direct cost for supervision      %    15.00

  Total number of workers:                    #     7.00
  Total crew wage (Per hour):                 $   108.06
  Direct labor cost:                          $   151.28
  Supervision and overhead:                   $    22.69
  Labor cost (Subtotal):                      $   173.98
  Total operating cost (Operating+Labor):     $   434.88
```

Table B5 - Summary of Labor Costs including delays

```
                     Labor Costs

  Travel time per day (Hours)              #        2.00
  Percent of direct cost for supervision   %       15.00


  Total crew wage (Per hour):              $      104.89
  Direct labor cost:                       $      183.56
  Supervision and overhead:                $       27.53
  Labor cost (Subtotal):                   $      211.09
  Total operating cost (Operating+Labor):  $      472.00
```

Additional Support Equipment

Caterpillar 966 front-end loader

The cost summary for operating the Caterpillar 966 loader is given in Table B6.

Table B6 - Cost Summary for the Caterpillar 966 Loader

```
------------------------- Summary-------------------------

  *** Caterpillar 966 Front-end Loader with Operator ***

Ownership
     Depreciable value:                 $ 144,480.00
     Equipment depreciation:            $  14,448.00 / Year
     Interest expense:                  $  14,688.00 / Year
     Taxes, license, insur. & storage:  $   2,350.08 / Year
     Annual ownership cost:             $  31,486.08 / Year
     Ownership cost (Subtotal):         $      19.68 / Hour
Machine operating
     Repairs and maintenance:           $       8.13 / Hour
     Fuel and oil:                      $       9.36 / Hour
     Lines and rigging:                 $       0.00 / Hour
     Tires or tracks:                   $       0.40 / Hour
     Equip. operating cost (Subtotal):  $      17.89 / Hour
Labor
     Direct labor cost:                 $      19.60 / Hour
     Supervision and overhead:          $       2.94 / Hour
     Labor cost (Subtotal):             $      22.54 / Hour

 OWNERSHIP COST                         $      19.68 / Hour
 OPERATING COST                         $      17.89 / Hour
 LABOR COST                             $      22.54 / Hour

 Machine rate (Owner. + Oper. + Labor)  $      60.11 / Hour
```

Crew Vehicle

A $20,000 crew rig was appraised for the use of the helicopter crew. All the operating costs are estimated on a helicopter flight-hour basis. A summary of the costs can be found in Table B7.

Table B7 - Cost Summary for Crew Vehicle

------------------------ Summary ------------------------

*** Crummy for Lama Support Crew - Cost based on Hel. hours ***

Ownership			
Depreciable value:	$	15,000.00	
Equipment depreciation:	$	3,000.00	/ Year
Interest expense:	$	1,700.00	/ Year
Taxes, license, insur. & storage:	$	544.00	/ Year
Annual ownership cost:	$	5,244.00	/ Year
Ownership cost (Subtotal):	$	2.38	/ Hour
Machine operating			
Repairs and maintenance:	$	0.09	/ Hour
Fuel and oil:	$	0.57	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	0.45	/ Hour
Equip. operating cost (Subtotal):	$	1.11	/ Hour
Labor			
Direct labor cost:	$	0.00	/ Hour
Supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	2.38	/ Hour
OPERATING COST	$	1.11	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Owner. + Oper. + Labor)	**$**	**3.50**	**/ Hour**

Detailed Time Study Form

An example of the form used to collect data during the detailed time study is included in figure D1.

Description of Turn Time Elements

Yardout - the yardout element consisted of that time between the unhook and hook elements. It represents the time it took for the helicopter to travel from the landing site to the point at which the next turn was attached. Yardout would begin as soon as the helicopter was in full acceleration towards the hook site. The researcher considered this time to be when the helicopter's attitude had changed from the nearly horizontal position during unhook to a pronounced angle towards the unit. The end of this element was considered to be that time when the attitude of the helicopter again changed back to a more or less horizontal position near the hook site.

Hook - the hook element consisted of that time between the yardout and yardin elements. It represents the time it took for the pilot to locate the choker setter, the choker setter to successfully hook the turn, and for the pilot/helicopter to maneuver up and out of the residual stand with the turn. Hook would begin when the attitude of the helicopter had changed from a pronounced forward pitch to a nearly horizontal position. The end of this element was that point in time when the helicopter would again change to a pronounced forward pitch towards the landing. This element contained a number of delays due to hung-up trees, weight problems, etc. however the researcher could not locate close enough to view them and keep track of them separately.

Yardin - the yardin element consisted of that time between the hook and unhook elements. It represents the time it took for the helicopter to travel from the hook site to the landing with the turn of logs. The beginning and ending of this element was determined in the same manner as for yardout, i.e. attitude of the helicopter.

Unhook - the unhook element consisted of that time between the yardin and yardout elements. It represents the time it took for the helicopter to locate directly over the landing, safely drop the turn of logs, and turn around so that it was again heading back to the unit. The beginning and ending of this element was determined as mentioned before.

Mechanics Vehicle and Tools

A $30,000 mechanics vehicle was appraised for. This would include the cost of the tools necessary to do routine maintenance on the helicopter. All the operating costs are estimated on a helicopter flight-hour basis. A summary of the cost can be found in Table B8.

Table B8 - Summary of Costs for the Mechanic's Vehicle and Tools

```
------------------------ Summary ------------------------

           *** Mechanic's Vehicle and Tools ***

Ownership
     Depreciable value:                   $   23,000.00
     Equipment depreciation:              $    4,600.00 / Year
     Interest expense:                    $    2,550.00 / Year
     Taxes, license, insur. & storage:    $      816.00 / Year
     Annual ownership cost:               $    7,966.00 / Year
     Ownership cost (Subtotal):           $        3.62 / Hour
Machine operating
     Repairs and maintenance:             $        0.14 / Hour
     Fuel and oil:                        $        0.57 / Hour
     Lines and rigging:                   $        0.00 / Hour
     Tires or tracks:                     $        0.45 / Hour
     Equip. operating cost (Subtotal):    $        1.16 / Hour
Labor
     Direct labor cost:                   $        0.00 / Hour
     Supervision and overhead:            $        0.00 / Hour
     Labor cost (Subtotal):               $        0.00 / Hour

 OWNERSHIP COST                           $        3.62 / Hour
 OPERATING COST                           $        1.16 / Hour
 LABOR COST                               $        0.00 / Hour

 Machine rate (Owner. + Oper. + Labor)    $        4.78 / Hour
```

Breakdown of Total Hourly Costs for Helicopter Operation

Table B9 shows the breakdown for the total hourly costs for operation of the helicopter system.

Table B9 - Total Hourly Cost Summary - Helicopter

Equipment	Ownership	Operating	Labor	Total
Lama & crew	108.37	260.91	173.98	543.25
Cat 966	19.68	17.89	22.54	60.11
Crew rig	2.38	1.11	0.00	3.50
Mechanic's	3.62	1.16	0.00	4.78
Totals	134.05	281.07	196.52	611.64
Gross figures			233.63	648.75

Appendix C

Detailed Cost Analysis - Cable System

A standard method for appraising the cost of logging equipment was used to determine the hourly cost for the Thunderbird TMY 50 yarder and support equipment. Costs were taken from the Siuslaw National Forest's Timber Appraisal Handbook (1987). A summary of the total hourly cost for the Thunderbird and crew can be found in Table C1.

Table C1 - Summary of Total Hourly Costs for T-bird and crew

---------------------------- **Summary** ----------------------------

Thunderbird TMY 50 Yarder w/ Danebo Carriage and Supports			
Ownership			
Depreciable value:	$	319,950.00	
Equipment depreciation:	$	39,993.75	/ Year
Interest expense:	$	32,371.48	/ Year
Taxes, license, insur. & storage:	$	7,769.16	/ Year
Annual ownership cost:	$	80,134.39	/ Year
Ownership cost (Subtotal):	$	50.08	/ Hour
Machine operating			
Repairs and maintenance:	$	12.50	/ Hour
Fuel and oil:	$	15.31	/ Hour
Lines and rigging:	$	7.39	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equip. operating cost (Subtotal):	$	35.19	/ Hour
Labor			
Direct labor cost:	$	107.83	/ Hour
Supervision and overhead:	$	16.17	/ Hour
Labor cost (Subtotal):	$	124.00	/ Hour
OWNERSHIP COST	$	50.08	/ Hour
OPERATING COST	$	35.19	/ Hour
LABOR COST	$	124.00	/ Hour
Machine rate (Owner. + Oper. + Labor)	**$**	**209.28**	**/ Hour**

Additional Support Equipment

Landing Cat

A used Caterpillar D6 bulldozer was part of the appraised cable yarding system. The summary of its operating costs can be found in Table C2.

Table C2 - Summary of Operating Costs for the Landing Cat

------------------------- Summary -----------------------

***** D6 Cat - (used and util. 20% of time) *****

Ownership			
Depreciable value:	$	71,890.00	
Equipment depreciation:	$	14.378.00	/ Year
Interest expense:	$	6,379.25	/ Year
Taxes, license, insur. & storage:	$	1,531.27	/ Year
Annual ownership cost:	$	22,288.27	/ Year
Ownership cost (Subtotal):	$	13.93	/ Hour
Machine operating			
Repairs and maintenance:	$	1.80	/ Hour
Fuel and oil:	$	1.53	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equip. operating cost (Subtotal):	$	3.33	/ Hour
Labor			
Direct labor cost:	$	0.00	/ Hour
Supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	13.93	/ Hour
OPERATING COST	$	3.33	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Owner. + Oper. + Labor)	**$**	**17.26**	**/ Hour**

Crew Rig and Mechanics Rig

Both the crew and mechanics vehicles were considered to cost the same as those for the helicopter operation. See Appendix B for information.

Breakdown of Total Hourly Costs for Cable Operation

Table C3 provides a breakdown of the hourly costs to operate the cable system.

Table C3 - Breakdown of Total Hourly Costs

Equipment	Ownership	Operating	Labor	Total
T-bird	50.08	35.19	124.00	209.28
D6 - cat	13.93	3.33	0.00	17.26
Crew rig	2.38	1.11	0.00	3.49
Mechanic's	3.62	1.16	0.00	4.78
Totals	70.01	40.79	124.00	234.81

Appendix D

Regression Analysis

Hook Times

Table D1 shows the results of a multiple regression analysis to determine a relationship between weights, choker delivery, and hook times. A total of 236 turns had a record of hook time, weight, and choker delivery.

Table D1 - Summary of Regression Analysis for Hook Times

Independent Variable	coeff.	stnd. error	t-value	sig.level
Constant	21.393274	5.774613	3.7047	0.0003
Weight	2.052894	0.311663	6.5869	0.0000
Chokers	22.658839	4.713811	4.8069	0.0000

R-squared = 0.2247

SE = 21.855235 (standard deviation of the error)

Haul Times

Table D2 shows the results of a simple linear regression analysis to determine a relationship between yarding distance and haul times. A total of 228 turns had complete records for haul time and distance.

Table D2 - Summary of Regression Analysis for Haul Time

```
    Regression Analysis to Determine the Relationship
          Between Haultime and Yarding Distance
    ------------------------------------------------

Regression Analysis - Linear model: Y = a+bX

-----------------------------------------------------------
Dep. variable: HAULTIME           Ind. variable: DISTANCE
-----------------------------------------------------------
                           Standard            T        Prob.
Parameter      Estimate     Error            Value      Level
-----------------------------------------------------------
Intercept        10.264    4.98923          2.05724    .04081
Slope         0.0168951  1.87225E-3         9.02398    .00000
-----------------------------------------------------------
                      Analysis of Variance
-----------------------------------------------------------
                                     Mean                 Prob
Source       Sum of Squares  Df     Square     F-Ratio   Level
Model           3564.5430     1   3564.5430     81.432  .00000
Error           9936.5050   227     43.7731
-----------------------------------------------------------
Total(Corr)  13501.048      228

Correlation Coefficient = 0.513828
R-squared = 26.40 percent
Stnd. Error of Est. = 6.61613  (est. stnd. dev. of error)
```

Total Turn Time Analysis

The total turn time regression equation was obtained by adding the regression equation for hook times, the regression equation for haul times, and the average unhook time (9.08 sec.). This approach was used after attempts to use multiple regression analysis directly failed to find an equation with reasonable R-squared values (the best was approximately 11%). The R-square value for the composite equation was calculated by using the equation to predict total turn times and then comparing these values with the actual that were measured. Using the standard equation for R-square (1-SSRes/SSTo) the R-square value for the composite equation was found to equal .26.

A complete list of the turns with all elements and independent variables measured can be found in Table D3. The Total Turn Time equation is also shown, along with the resulting predicted values for turn time and R-square.

Determination of Average MBF/Log and Lb/BF

The relationships for both mbf per average log and pounds per board feet were needed to estimate production with the total turn time equation. Because the study area was fairly homogeneous in terms of tree size the average log size from the scale information provided by the District was used. From the time study information it was known that the average turn consisted of 1.43 logs and weighed 1780 pounds. Given this information an estimate of pounds per board foot could be derived and was equal to 14.27.

from scale:

total logs (gross) = 4648

total gross scale = 405.42 mbf

average bf/log = 405.42/4648 = 87.22 bf

from study:

ave. turn weight = 1780 lbs.

ave. logs per turn = 1.43

ave. logs per turn * ave. log = 124.72 bf per turn

ave. weight / ave. bf. = 1780 / 124.72 = 14.27 lb/bf.

Effective Hours

The Ridge unit had a total of 12 skyline roads planned. Thirteen intermediate supports were required at heights up to 50 feet and nearly every skyline road required the rigging of a tail tree as high as 60 feet. Because of this the rigging complexity of the TMY 50 system is much greater than in Hochrein's study. By using the effective hours estimate from Hochrein's study the cost of delays may be underestimated. Kellogg (1980) has shown that road changing times were not significantly increased using intermediate supports when those supports could be "pre-rigged". It is assumed that for the Ridge unit intermediate supports will be "pre-rigged" and the estimate of effective hours calculated by Hochrein will be a reasonably accurate estimate.

Hochrein had two estimates for effective hours. One estimate was based on delays during the time studies (.736), the other was based on shift level data (.519). Both estimates accounted for all types of delays including road and landing changes. The shift level estimate will be used for this study since it is based on a larger sample of delay events and therefore probably more accurate. Using this estimate the effective hour =.519 * 60 min. = 31.14 minutes.

Turn Size

Ave max. payload = 7000 lbs. (from profile analysis)
Load factor = .60 (estimate)
Ave. Max Payload * Load factor = Average Payload = 4200 lbs.
lbs/bf = 14.27 (calculated as shown in appendix D)

Board feet/turn = 4200 lbs./14.27 lbs/b.f. = 294 bf/turn
Cubic feet/turn = 294 bf/4.76 bf/cf = 61.8 cf/turn
Pieces/turn = 294 bf/87.2 bf/piece = 3.4 pieces

Production

Turns/effective hour = (min./effective hour) / (min./turn)
= 31.14 min. / 5.88 min. = 5.30 turns
Volume/effective hour = (turns/effective hour) * (vol./turn)
= 5.30 turns * 294 b.f. = 1558 b.f./eff.hour (gross scale)
Net Scale Volume/effective hour = (gross/hour) * (net/gross)
= 1558 b.f./eff.hour * .944 net/gross = 1471 b.f./eff.hour
Net c.f./eff.hour = 1471/4.75 = 310 c.f./ eff.hour

Cost

$/mbf = $ 234.80/hr (appendix C) / 1.47 mbf = $ 159.73

$/cunit = $ 234.80 / 3.10 cunits = $ 75.74

Comparison of Study Conditions

The following chart shows a comparison of study conditions between Peter Hochrein's study and the hypothetical cable system used for this study.

Table E1 - Comparison of Hochrein and Ridge Units

	Hochrein			Ridge T.S.	
	ave.	range		ave.	range
Tot Vol/ac mbf	21			33	
Tot Vol/ac cun	50			69	
Vol remove mbf	8.3			9.8	
Vol remove cun	19.3			21	
Total Trees/ac	350			190	
Cut Trees/ac	99			52	
Average dbh	11.4			14.9	
Slope	49	10-75		40	35-60
Ave piece b.f.	59.6			87.2	
Ave piece c.f.	13.77			18.18	
Yarder/span	Madill71	single		TMY 50	multispan
Yarding Dist.	516	75-1150		756	0-2200
Lat Yard Dist.	42	0-150		35	0-120
Pieces/turn*	4.05	1-11		3.4	
Turn vol b.f.*	242			294	
Turn vol c.f.*	55.7			61.8	
Choker setters	2.7	1-4		2.5	2-3

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* Turn info. for Ridge T.S. was estimated as shown in previous section.

Evaluation of the Total Turn Time Regression Equation

Total Turn Tim40.737274 + 0.0168951*Distance + 2.052894*Weight + 22.658839*Chokers

turn #	yardout	hook	yardin	unhook	pieces	weight	loc.	chok	newloc	dist	total	haultime	predict	SResid	STo
192	23	34	26	11	2	14	1	0	0	2500	94	49	111.72	313.84	940.65
193	21	40	20	11	1	14	1	0	0	2500	92	41	111.72	388.70	1067.33
194	23	44	22	10	2	17	1	0	0	2500	99	45	117.87	356.24	658.95
195	21	60	20	11	2	14	1	0	0	2500	112	41	111.72	0.08	160.53
196	25	41	23	16	2	20	1	0	0	2500	105	48	124.03	362.25	386.91
197	27	55	27	11	1	13	1	1	0	2500	120	54	132.32	151.82	21.81
198	23	57	28	11	2	13	3	0	1	2700	119	51	113.04	35.50	32.15
199	24	57	24	10	3	12	3	0	0	2700	115	48	110.99	16.09	93.51
200	23	88	22	10	3	20	3	0	0	2700	143	45	127.41	242.99	335.99
201	25	57	25	10	2	10	3	0	0	2700	117	50	106.88	102.35	58.83
202	23	45	22	10	1	13	3	0	0	2700	100	45	113.04	170.09	608.61
203	26	123	15	11	1	27	3	0	0	2700	175	41	141.78	1103.42	2533.11
204	22	59	23	10	1	22	3	0	0	2700	114	45	131.52	306.87	113.85
205	30	63	22	6	1	27	3	0	0	2700	121	52	141.78	431.90	13.47
206	27	140	23	8	1	27	3	0	0	2700	198	50	141.78	3160.44	5377.29
207	33	59	23	9	2	18	3	0	0	2700	124	56	123.31	0.48	0.45
208	24	121	32	10	1	27	3	1	0	2700	187	56	164.44	508.91	3885.03
209	24	90	25	13	1	24	3	0	0	2700	152	49	135.62	268.19	746.93
210	29	50	28	10	1	26	4	0	0	3100	117	57	146.49	869.50	58.83
211	33	47	28	11	2	24	5	0	1	3100	119	61	142.38	546.70	32.15
212	34	32	32	8	1	15	5	0	0	3100	106	66	123.91	320.61	348.57
213	36	44	33	7	2	16	5	0	0	3100	120	69	125.96	35.50	21.81
214	24	38	26	12	2	11	6	0	1	2300	100	50	102.18	4.74	608.61
215	21	31	29	9	1	17	6	0	0	2300	90	50	114.50	600.01	1202.01
216	23	85	16	8	2	22	6	0	0	2300	132	39	124.76	52.42	53.73
217	29	44	26	8	1	16	4	0	1	3100	107	55	125.96	359.42	312.23
218	32	61	32	10	2	18	4	0	0	3100	135	64	130.06	24.36	106.71
219	32	38	33	8	1	17	4	0	0	3100	111	65	128.01	289.38	186.87
220	31	53	34	8	1	16	5	0	1	3100	126	65	125.96	0.00	1.77
221	31	69	30	9	2	15	5	0	0	3100	139	61	123.91	227.84	205.35
222	34	39	31	14	1	18	5	0	0	3100	118	65	130.06	145.84	44.49
226	35	40	33	8	1	20	4	0	0	3100	116	68	134.17	330.15	75.17
227	36	64	22	11	1	15	4	1	0	3100	133	58	146.56	183.99	69.39
228	36	36	36	5	1	16	5	0	1	3100	113	72	125.96	167.92	136.19
229	34	55	34	7	2	18	5	1	0	3100	130	68	152.72	516.34	28.41
230	31	47	33	9	1	17	5	0	0	3100	120	64	128.01	64.18	21.81
231	26	45	28	7	1	14	6	0	1	2300	106	54	108.34	5.46	348.57
232	23	74	28	15	1	22	6	0	0	2300	140	51	124.76	232.27	235.01
233	24	40	34	6	2	15	6	0	0	2300	104	58	110.39	40.82	427.25
234	23	51	31	7	1	12	6	0	0	2300	112	54	104.23	60.36	160.53
235	32	39	35	6	2	13	4	0	1	3100	112	67	119.80	60.84	160.53
236	28	40	36	7	1	15	4	0	0	3100	111	64	123.91	166.55	186.87
237	32	59	32	6	2	18	4	0	0	3100	129	64	130.06	1.13	18.75
238	31	54	31	11	2	18	5	0	1	3100	127	62	130.06	9.39	5.43
239	32	59	33	6	1	26	5	0	0	3100	130	65	146.49	271.83	28.41
240	36	36	34	8	1	9	5	0	0	3100	114	70	111.59	5.82	113.85
241	26	53	33	6	1	17	6	0	1	2300	118	59	114.50	12.28	44.49
242	25	59	25	11	1	18	6	0	0	2300	120	50	116.55	11.92	21.81
243	22	82	29	6	1	14	6	0	0	2300	139	51	108.34	940.25	205.35
244	32	39	32	7	1	12	4	0	1	3100	110	64	117.75	60.01	215.21

Table D3 - Turn Time Regression

Evaluation of the Total Turn Time Regression Equation

Total Turn Tim40.737274 + 0.0168951*Distance + 2.052894*Weight + 22.658839*Chokers

turn #	yardout	hook	yardin	unhook	pieces	weight	loc.	chok	newloc	dist	total	haultime	predict	SResid	STo
245	30	56	36	17	1	18	4	0	0	3100	139	66	130.06	79.85	205.35
246	30	94	32	7	2	16	4	0	0	3100	163	62	125.96	1372.08	1469.19
247	29	65	33	9	1	20	5	0	1	3100	136	62	134.17	3.35	128.37
248	27	38	36	10	1	18	5	0	0	3100	111	63	130.06	363.44	186.87
249	32	85	30	8	1	22	5	1	0	3100	155	62	160.93	35.22	919.91
250	23	47	27	8	1	12	6	0	1	2300	105	50	104.23	0.59	386.91
251	22	43	29	10	1	18	6	0	0	2300	104	51	116.55	157.45	427.25
252	20	58	27	10	2	15	6	0	0	2300	115	47	110.39	21.26	93.51
253	31	43	34	6	1	21	4	0	1	3100	114	65	136.22	493.86	113.85
254	34	20	35	9	1	15	4	0	0	3100	98	69	123.91	671.09	711.29
255	28	68	33	5	1	18	4	0	0	3100	134	61	130.06	15.49	87.05
257	28	64	29	10	1	21	5	0	0	3100	131	57	136.22	27.28	40.07
258	28	47	35	7	2	21	5	0	0	3100	117	63	136.22	369.52	58.83
259	20	53	29	7	1	15	6	0	1	2300	109	49	110.39	1.93	245.55
260	23	59	27	9	2	9	6	0	0	2300	118	50	98.07	397.12	44.49
261	25	93	28	10	2	21	6	1	0	2300	156	53	145.37	113.09	981.57
262	32	72	29	8	2	12	6	0	0	2300	141	61	104.23	1351.98	266.67
263	33	68	37	7	1	17	4	0	1	3100	145	70	128.01	288.62	413.31
264	30	72	35	10	1	17	4	0	0	3100	147	65	128.01	360.57	498.63
265	29	81	37	10	2	26	5	0	0	3100	157	66	146.49	110.52	1045.23
266	32	55	39	12	1	15	5	0	0	3100	138	71	123.91	198.66	177.69
267	31	71	39	11	1	24	5	0	0	3100	152	70	142.38	92.51	746.93
268	25	53	31	11	1	12	6	0	1	2300	120	56	104.23	248.67	21.81
269	27	82	30	7	2	16	6	0	0	2300	146	57	112.44	1126.12	454.97
											124.67		SSResid97578.35		

SSTo = 132511.7

R-squared = 1 - SSResid/SSTo = 0.263624

Evaluation of the Total Turn Time Regression Equation

Tottal Turn Tim40.737274 + 0.0168951*Distance + 2.052894*Weight + 22.658839*Chokers

tumn #	yardout	hook	yardin	unhook	pieces	weight	loc.	chok	newloc	dist	total	haultime	predict	SResid	STo
77	29	31	29	7	1	13	3	0	0	2700	96	58	113.04	290.42	821.97
78	37	32	29	8	1	12	3	0	0	2700	106	66	110.99	24.89	348.57
81	31	37	30	8	2	16	3	0	0	2700	106	61	119.20	174.25	348.57
82	26	49	27	9	3	15	3	0	0	2700	111	53	117.15	37.79	186.87
83	25	130	23	13	1	25	3	0	0	2700	191	48	137.68	2843.41	4399.67
84	23	42	29	10	1	23	3	0	0	2700	104	52	133.57	874.42	427.25
85	31	98	30	10	2	12	3	1	0	2700	169	61	133.65	1249.79	1965.15
86	22	46	27	9	1	18	1	0	1	2500	104	49	119.93	253.67	427.25
87	24	59	31	11	1	15	1	0	0	2500	125	55	113.77	126.15	0.11
88	25	61	35	9	1	21	1	0	0	2500	130	60	126.09	15.32	28.41
89	26	39	30	12	1	24	1	0	0	2500	107	56	132.24	637.28	312.23
90	27	41	25	14	1	18	1	0	0	2500	107	52	119.93	167.11	312.23
91	28	37	32	9	1	24	1	0	0	2500	106	60	132.24	688.77	348.57
92	26	58	29	8	1	23	1	0	0	2500	121	55	130.19	84.49	13.47
93	25	58	27	9	1	24	1	0	0	2500	119	52	132.24	175.42	32.15
94	23	49	42	7	1	26	1	0	0	2500	121	65	136.35	235.63	13.47
95	16	53	29	9	3	12	1	0	0	2500	107	45	107.61	0.37	312.23
96	29	53	31	9	1	17	1	1	0	2500	122	60	140.53	343.47	7.13
97	24	42	27	6	1	20	1	0	0	2500	99	51	124.03	626.65	658.95
98	26	47	29	9	1	24	3	0	1	2700	111	55	135.62	606.32	186.87
99	26	70	28	8	1	21	3	0	0	2700	132	54	129.46	6.43	53.73
100	24	46	32	7	1	22	3	0	0	2700	109	56	131.52	507.05	245.55
101	24	42	30	9	1	23	3	0	0	2700	105	54	133.57	816.28	386.91
102	24	53	27	10	1	15	3	0	0	2700	114	51	117.15	9.91	113.85
103	23	37	27	11	1	12	3	0	0	2700	98	50	110.99	168.71	711.29
104	23	43	29	10	1	24	3	0	0	2700	105	52	135.62	937.80	386.91
106	30	65	32	8	1	18	3	0	0	2700	135	62	123.31	136.75	106.71
109	21	51	31	8	2	23	1	0	0	2500	111	52	130.19	368.32	186.87
110	24	53	26	6	1	20	1	0	0	2500	109	50	124.03	225.99	245.55
111	21	49	30	6	2	20	1	0	0	2500	106	51	124.03	325.19	348.57
112	24	49	24	8	2	19	1	0	0	2500	105	48	121.98	288.32	386.91
113	25	49	24	11	2	14	1	0	0	2500	109	49	111.72	7.37	245.55
114	22	41	26	10	1	22	1	0	0	2500	99	48	128.14	849.06	658.95
115	22	90	30	8	1	29	1	0	0	2500	150	52	142.51	56.12	641.61
116	26	87	27	14	1	25	1	1	0	2500	154	53	156.96	8.74	860.25
117	23	73	32	9	1	14	3	0	1	2700	137	55	115.09	479.85	152.03
118	26	93	28	7	1	13	3	0	0	2700	154	54	113.04	1677.59	860.25
119	32	55	26	8	2	12	3	0	0	2700	121	58	110.99	100.22	13.47
120	26	37	32	11	1	21	3	0	0	2700	106	58	129.46	550.60	348.57
121	27	62	21	10	1	23	3	0	0	2700	120	48	133.57	184.16	21.81
122	25	59	26	11	1	22	3	0	0	2700	121	51	131.52	110.62	13.47
123	23	49	26	11	2	18	3	0	0	2700	109	49	123.31	204.67	245.55
124	28	61	29	10	2	17	3	1	0	2700	128	57	143.91	253.19	11.09
125	29	33	28	7	1	13	1	0	1	2500	97	57	109.66	160.34	765.63
126	25	54	28	14	2	17	1	0	0	2500	121	53	117.87	9.77	13.47
127	22	54	27	9	1	19	1	0	0	2500	112	49	121.98	99.60	160.53
128	21	86	24	10	1	22	1	0	0	2500	141	45	128.14	165.41	266.67
129	18	62	26	8	1	23	1	0	0	2500	114	44	130.19	262.17	113.85
130	21	41	25	8	1	17	1	0	0	2500	95	46	117.87	523.23	880.31
131	20	84	24	10	1	22	1	0	0	2500	138	44	128.14	97.25	177.69

Table D3 - Turn Time Regression

Evaluation of the Total Turn Time Regression Equation

Total Turn Tim40.737274 + 0.0168951*Distance + 2.052894*Weight + 22.658839*Chokers

turn #	yardout	hook	yardin	unhook	pieces	weight	loc.	chok	newloc	dist	total	haultime	predict	SResid	STo
132	21	104	22	11	1	25	1	0	0	2500	158	43	134.30	561.81	1110.89
133	22	46	27	12	1	22	1	0	0	2500	107	49	128.14	446.84	312.23
134	24	98	27	10	1	28	1	1	0	2500	159	51	163.11	16.93	1178.55
135	23	76	29	7	1	25	3	0	1	2700	135	52	137.68	7.16	106.71
136	22	170	27	8	1	28	3	0	0	2700	227	49	143.84	6916.40	10471.43
137	36	45	25	10	1	22	3	0	0	2700	116	61	131.52	240.80	75.17
138	21	37	25	11	2	11	3	0	0	2700	94	46	108.94	223.08	940.65
139	22	44	27	9	1	17	3	0	0	2700	102	49	121.25	370.69	513.93
140	22	55	26	12	2	24	3	0	0	2700	115	48	135.62	425.33	93.51
142	23	45	38	7	2	11	3	0	0	2700	113	61	108.94	16.52	136.19
143	24	48	25	9	2	12	3	0	0	2700	106	49	110.99	24.89	348.57
144	25	76	26	13	1	22	3	1	0	2700	140	51	154.18	200.97	235.01
145	26	71	31	13	3	17	1	0	1	2500	141	57	117.87	534.80	266.67
146	23	45	23	11	1	13	1	0	0	2500	102	46	109.66	58.72	513.93
147	24	48	27	9	2	12	1	0	0	2500	108	51	107.61	0.15	277.89
148	23	95	37	7	2	24	1	0	0	2500	162	60	132.24	885.39	1393.53
149	23	82	30	9	1	25	1	0	0	2500	144	53	134.30	94.14	373.65
150	23	101	25	8	1	25	1	0	0	2500	157	48	134.30	515.41	1045.23
151	24	104	22	9	1	25	1	0	0	2500	159	46	134.30	610.22	1178.55
152	21	54	26	12	2	17	1	0	0	2500	113	47	117.87	23.76	136.19
153	20	85	37	8	1	23	1	0	0	2500	150	57	130.19	392.37	641.61
154	21	114	22	16	2	12	1	0	0	2500	173	43	107.61	4275.88	2335.79
155	25	117	22	10	1	18	1	1	0	2500	174	47	142.59	986.84	2433.45
156	26	96	23	12	1	22	3	0	1	2700	157	49	131.52	649.35	1045.23
157	24	77	28	10	1	21	3	0	0	2700	139	52	129.46	90.92	205.35
158	25	44	25	9	2	15	3	0	0	2700	103	50	117.15	200.15	469.59
159	30	47	26	10	1	20	3	0	0	2700	113	56	127.41	207.70	136.19
160	30	41	25	9	1	18	3	0	0	2700	105	55	123.31	335.11	386.91
161	25	104	25	10	1	16	3	0	0	2700	164	50	119.20	2007.01	1546.85
162	29	42	25	10	3	13	3	0	0	2700	106	54	113.04	49.59	348.57
163	24	56	24	11	1	20	3	0	0	2700	115	48	127.41	154.06	93.51
164	23	95	30	6	1	20	3	0	0	2700	154	53	127.41	706.93	860.25
165	23	54	22	12	1	21	3	0	0	2700	111	45	129.46	340.95	186.87
174	23	40	25	13	2	15	1	0	0	2500	101	48	113.77	163.03	560.27
175	21	76	27	9	2	14	1	0	0	2500	133	48	111.72	453.03	69.39
177	21	60	26	15	2	17	1	0	0	2500	122	47	117.87	17.02	7.13
178	24	55	22	10	1	18	1	1	0	2500	111	46	142.59	997.67	186.87
179	25	54	19	12	2	13	3	0	1	2700	110	44	113.04	9.25	215.21
180	23	80	29	9	2	10	3	0	0	2700	141	52	106.88	1163.97	266.67
181	22	57	25	10	3	12	3	0	0	2700	114	47	110.99	9.07	113.85
182	23	54	24	10	1	17	3	0	0	2700	111	47	121.25	105.13	186.87
183	24	58	24	10	1	20	3	0	0	2700	116	48	127.41	130.23	75.17
184	23	42	27	12	1	12	3	0	0	2700	104	50	110.99	48.84	427.25
185	27	36	28	11	2	13	3	0	0	2700	102	55	113.04	121.92	513.93
186	25	51	21	10	1	19	3	0	0	2700	107	46	125.36	337.05	312.23
187	27	73	24	12	2	17	3	1	0	2700	136	51	143.91	62.60	128.37
188	22	64	22	11	1	17	1	0	1	2500	119	44	117.87	1.27	32.15
189	22	112	20	11	1	20	1	0	0	2500	165	42	124.03	1678.30	1626.51
190	23	47	27	8	2	12	1	0	0	2500	105	50	107.61	6.81	386.91
191	25	67	26	11	3	19	1	0	0	2500	129	51	121.98	49.28	18.75

Table D3 - Turn Time Regression

Evaluation of the Total Turn Time Regression Equation

Total Turn Tim40.737274 + 0.0168951*Distance + 2.052894*Weight + 22.658839*Chokers

turn #	yardout	hook	yardin	unhook	pieces	weight	loc.	chok	newloc	dist	total	haultime	predict	SResid	STo
24	32	58	30	5	1	18	1	0	0	2500	125	62	119.93	25.73	0.11
25	28	81	33	15	1	28	1	0	0	2500	157	61	140.46	273.70	1045.23
26	29	48	35	8	1	25	1	0	0	2500	120	64	134.30	204.41	21.81
27	31	40	38	3	1	21	1	0	0	2500	112	69	126.09	198.41	160.53
28	33	37	28	4	2	17	3	0	0	2700	102	61	121.25	370.69	513.93
29	38	47	28	5	1	17	3	1	0	2700	118	66	143.91	671.44	44.49
30	27	64	33	4	2	13	1	0	1	2500	128	60	109.66	336.26	11.09
31	36	48	30	10	2	18	1	0	0	2500	124	66	119.93	16.59	0.45
32	35	48	28	12	2	15	1	0	0	2500	123	63	113.77	85.22	2.79
33	32	60	39	4	1	28	3	0	0	2700	135	71	143.84	78.06	106.71
35	39	180	35	7	1	25	3	1	0	2700	261	74	160.34	10133.40	18585.87
36	35	34	30	21	1	15	1	0	1	2500	120	65	113.77	38.83	21.81
37	29	58	33	6	2	14	1	1	0	2500	126	62	134.37	70.13	1.77
38	31	37	35	4	1	12	1	0	0	2500	107	66	107.61	0.37	312.23
39	26	50	34	6	1	15	1	0	0	2500	116	60	113.77	4.98	75.17
40	27	53	34	4	2	18	1	0	0	2500	118	61	119.93	3.71	44.49
41	25	68	29	7	2	11	3	0	0	2700	129	54	108.94	402.57	18.75
42	33	38	27	7	2	10	3	0	0	2700	105	60	106.88	3.55	386.91
43	28	56	30	9	1	21	3	0	0	2700	123	58	129.46	41.79	2.79
44	26	30	32	4	1	12	3	0	0	2700	92	58	110.99	360.57	1067.33
45	32	67	29	9	2	16	3	1	0	2700	137	61	141.86	23.61	152.03
46	25	43	37	4	1	14	1	0	1	2500	109	62	111.72	7.37	245.55
47	22	44	30	5	2	14	1	0	0	2500	101	52	111.72	114.82	560.27
48	24	57	28	6	2	17	1	0	0	2500	115	52	117.87	8.26	93.51
49	29	43	27	9	3	18	1	0	0	2500	108	56	119.93	142.26	277.89
50	23	49	28	9	2	15	1	0	0	2500	109	51	113.77	22.74	245.55
51	34	126	28	9	2	13	1	1	0	2500	197	62	132.32	4183.31	5231.63
52	37	25	33	7	1	18	1	0	0	2500	102	70	119.93	321.38	513.93
53	25	33	30	9	1	19	1	0	0	2500	97	55	121.98	624.00	765.63
54	31	47	30	7	1	21	1	0	0	2500	115	61	126.09	122.89	93.51
55	43	30	31	7	1	19	3	0	1	2700	111	74	125.36	206.18	186.87
56	27	52	30	6	1	12	3	0	0	2700	115	57	110.99	16.09	93.51
57	22	54	27	8	1	20	3	0	0	2700	111	49	127.41	269.35	186.87
58	36	45	30	8	2	18	3	0	0	2700	119	66	123.31	18.54	32.15
59	24	68	32	6	1	24	3	0	0	2700	130	56	135.62	31.62	28.41
60	32	111	34	7	1	21	3	0	0	2700	184	66	129.46	2974.09	3520.05
61	24	65	29	10	2	12	3	0	0	2700	128	53	110.99	289.38	11.09
62	22	48	28	7	1	18	3	0	0	2700	105	50	123.31	335.11	386.91
63	24	41	30	6	2	15	3	0	0	2700	101	54	117.15	260.74	560.27
64	26	54	32	5	1	18	3	0	0	2700	117	58	123.31	39.77	58.83
65	32	40	29	10	2	17	3	0	0	2700	111	61	121.25	105.13	186.87
66	32	80	35	14	1	28	3	1	0	2700	161	67	166.49	30.18	1319.87
67	20	76	30	8	1	28	1	0	1	2500	134	50	140.46	41.68	87.05
69	22	102	26	8	3	20	1	0	0	2500	158	48	124.03	1153.76	1110.89
70	26	67	31	9	2	17	1	0	0	2500	133	57	117.87	228.79	69.39
71	23	60	28	8	1	18	1	0	0	2500	119	51	119.93	0.86	32.15
72	23	54	27	17	1	12	1	0	0	2500	121	50	107.61	179.30	13.47
73	30	113	27	8	1	22	1	0	0	2500	178	57	128.14	2486.15	2844.09
74	28	68	32	10	1	20	1	0	0	2500	138	60	124.03	195.08	177.69
75	37	69	28	10	3	17	1	1	0	2500	144	65	140.53	12.02	373.65
76	22	39	25	9	1	14	3	0	1	2700	95	47	115.09	403.79	880.31

Table D3 - Turn Time Regression

HELICOPTER PRODUCTION STUDY

RIDGE TIMBER SALE RIGDON RANGER DISTRICT WILLAMETTE N.F.

OPERATOR: ROCKY MTN. HELICOPTERS PURCHASER: STARFIRE LMBR.

DATE: ____________________ SIGNATURE: ______________________________

H – HOOK U – UNHOOK YI – YARD IN YO – YARD OUT

CH – CHOKERS D – DELAY

ACT.	TIME	# PIECES	LOC.	ACT.	TIME	# PIECES	LOC.

Figure D1 – Example of the Detailed Time Study Form

Pay Period # 2
F.Y. 1988